Research into Environmental Pollution

Report of Five
WHO Scientific Groups

This report contains the collective views of
international groups of experts and does not necessarily
represent the decisions or the stated policy of the
World Health Organization.

GENEVA
1968

The World Health Organization (WHO) is one of the specialized agencies in relationship with the United Nations. Through this organization, which came into being in 1948, the public health and medical professions of more than 120 countries exchange their knowledge and experience, and collaborate in an effort to achieve the highest possible level of health throughout the world. WHO is not concerned with problems that individual countries or territories can solve with their own resources. It deals, rather, with problems that can be satisfactorily solved only through the co-operation of all or several countries—for example, the eradication or control of malaria, schistosomiasis, smallpox, and other communicable diseases, as well as some cardiovascular diseases and cancer. Progress towards better health throughout the world also demands international co-operation in many other activities : for example, setting up international standards for biological substances, for pesticides and for pesticide spraying equipment ; compiling an international pharmacopoeia ; drawing up and administering the International Sanitary Regulations ; revising the international lists of diseases and causes of death ; assembling and disseminating epidemiological information ; recommending non-proprietary names for drugs ; and promoting the exchange of scientific knowledge. In many parts of the world there is need for improvement in maternal and child health, nutrition, nursing, mental health, dental health, social and occupational health, environmental health, public health administration, professional education and training, and health education of the public. Thus a large share of the Organization's resources is devoted to giving assistance and advice in these fields and to making available—often through publications—the latest information on these subjects. Since 1958 an extensive international programme of collaborative research and research co-ordination has added substantially to the knowledge in many fields of medicine and public health. This programme is constantly developing and its many facets are reflected in WHO publications.

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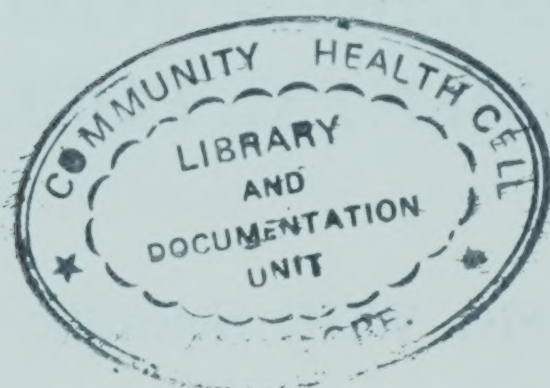# RESEARCH INTO ENVIRONMENTAL POLLUTION

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RESEARCH INTO ENVIRONMENTAL POLLUTION

Report of Five WHO Scientific Groups

INTRODUCTION

Contamination of air, soil, food and water by inorganic chemicals and sewage has received attention in the past and no doubt will continue to do so in the future. Less attention has been devoted to the problems that may follow the introduction into the environment of the organic chemicals that man synthesizes for specific purposes.

Annually, hundreds of new organic chemicals are made; some of them are persistent substances; many of them are used on a world-wide scale. They include new plastics and plasticizers; synthetic detergents and solvents; additives to foods, fuels or alloys; and pesticides. To an increasing extent, synthetic chemicals are used in households, appliances and furnishings, clothing and building materials. Many of them enter directly or indirectly into food, and more may reach surface and underground water supplies and be released into the atmosphere.

It is advisable to consider the different types of air, water and soil pollution together rather than separately. There are many instances in which air, water and soil are polluted by the same type of waste. The dumping of molten slag from a steel blast furnace, for example, results in an immediate liberation of gases, the eventual pollution of streams by leaching from rainfall, and an alteration of the land surface that hinders subsequent beneficial use of the soil. There are other situations in which the prevention of one form of pollution leads to another. Cyanides, for example, can be removed from the liquid wastes of electroplating plants by acidification and aeration, but the result is pollution of the atmosphere by hydrogen cyanide.

Regulations designed for public health protection are sometimes based on the assumption that there is only one route of exposure for the substance in question. Such an assumption is generally false and it is becoming increasingly obvious that pollution exposures from all sources should be evaluated together.

Pollution of air, water or soil may also adversely affect the quality of foodstuffs. Indeed, the food chain is undoubtedly the major vehicle

for the transfer of radioactive contamination and pesticide residues to man.

Pollution seems to be an inevitable consequence of modern industrial technology, rapid and convenient transport, and comfortable housing, but excessive pollution may interfere with man's health and his mental, social and economic well-being. The problem, then, is to determine the level of pollution that permits optimum economic and social development without presenting hazards to health.

In order to obtain an overall view of existing knowledge of the biological aspects of environmental pollution and guidance as to the further research needed, WHO convened five Scientific Groups between March 1963 and November 1965. The principal aspects considered were microchemical pollution of water systems, biological estimation of water pollution levels, identification and measurement of air pollutants, and the long-term effects on health of new pollutants. In addition, one group was concerned specifically with research into environmental pollution.

The reports of the five Scientific Groups have been edited and consolidated, and the consolidated report is presented in the following pages.

1. BASIC CONCEPTS IN THE EVALUATION OF ENVIRONMENTAL HAZARDS

In considering the long-term effects on health of low levels of contaminants in man's environment, some fundamental biological principles involved in the fate of these substances in or on the human body, and their effect on the different bodily functions, must be discussed.

The problems are complex and much basic general information is still needed, in addition to specific information for individual substances.

These effects may be divided into two groups:

(1) localized effects at the place of contact and entry, chiefly the respiratory and alimentary systems, but to some extent the skin and conjunctivae, and

(2) effects after absorption and distribution inside the body.

LOCALIZED EFFECTS AT POINT OF CONTACT AND ENTRY

At the place of contact, absorption may be expected into the boundary zone of the organ, the outermost cells of which may be influenced in different ways. The normal biochemistry of the cells may show deviations, leading to the release of substances that are transported by the circulation to other parts of the body, eliciting stress reactions or interfering with metabolic processes elsewhere in the body. Alternatively, local structural changes may occur. Local contact may also give rise to local nervous stimulation or to effects on the central nervous system.

The local changes may give better protection to the organ or, by altering the conditions of absorption or penetration of foreign substances, may impair its natural defence mechanism.

Some facts are known about these contact effects but there are many gaps in the basic knowledge of the possible effects of long-term exposure. Little is known about the occurrence of specific protective substances.

ABSORPTION AND DISTRIBUTION

Absorbed chemicals interfere with the biochemistry of the cells only if some chemical reaction takes place. Storage of insoluble substances may limit the amount of pollutant available for such reactions. Storage may thus have the effect of excluding pollutants from vital biochemical processes. Some elements and radicals are chemically the same as the normal constituents or are so like them that they are treated as such, and thus may disturb the normal biochemical processes, or the pollutants may be degraded or metabolized to substances which are then excreted. In some instances, new toxic substances are produced inside the body.

If man did not have such biochemical mechanisms to take care of foreign substances entering the body, he would have succumbed to the many substances in nature that are foreign to him but are known to penetrate into his body; many of these are harmful when absorbed in large doses. This agrees with the experience that all toxic substances so far investigated (with the possible exception of mutagenic, teratogenic or carcinogenic substances) have been found in experimental animals to have — even with prolonged exposure — a minimum dose-rate below which no detectable effect on health occurs within the normal life-span.

Most toxicological research has been carried out on the harmful effects of higher doses than these. For the evaluation of long-term effects however, it is important to know much more about biochemical reactions to smaller doses. Normal enzymes, especially in the liver, may detoxify

potentially harmful substances. For example, during chronic intake of DDT in man, the rate of its conversion to the much less toxic DDE has been found to increase. Thus the problem of induction of adaptive enzymes is of importance. The identification of the enzymes capable of removing chlorine and hydrogen from DDT and perhaps from other chlorinated organic compounds, and of those responsible for many other detoxifying biochemical processes, is an important field for additional research.

More basic knowledge about the general conditions of absorption, distribution, metabolism, storage and excretion will permit the development of better criteria for public health regulations.

IMPORTANCE OF NORMAL VARIABILITY

All biological processes and structures show variation within a "normal range" of variability. This reflects man's adaptation to his changing environmental conditions within the limits defined by his individual genetic make-up. If the effects of long-term exposures do not exceed this normal variation, no harmful consequences need be expected. Health hazards need be feared only if the adaptation forces and defence mechanisms are overburdened or overstimulated.

Many agents, both chemical and physical, confronting man provoke adaptive reactions. These biochemical and physiological reactions may either limit the capacity of the organism to adapt itself to the effects of other factors or stimulate the capacity for adaptation. These alternatives are important in the understanding of the health hazards of long-term exposure. Because of the importance of these adaptive mechanisms, experiments with combinations of pollutants and other stresses are greatly needed.

EFFECTS ON REGULATORY SYSTEMS

Besides the effects of pollutants at the cellular level leading to biochemical deviations and structural derangements, there may be effects on the homeostatic regulation of the body and stimulation or inhibition of the nervous system, the regulatory hormonal system, or the immunoreaction of the reticuloendothelial system.

Knowledge about these regulatory mechanisms is very scanty. Not every detectable effect in these processes has necessarily harmful or lasting consequences on health. Some reactions may be detectable now only because new techniques are providing more knowledge about the basic conditions of health and the processes of adaptation to the environment.

Other health-promoting measures may strengthen man's capacity to adapt himself to his changing living conditions. After all, man's ancestors have during the whole period of evolution adapted themselves to the changing conditions of life on this planet. Better nutrition, housing and environmental conditions might help man to bear the burdens of adapting to the physical and chemical agents to which he is exposed, but this, if true, must not be used as a reason for delaying the introduction of stricter requirements for air and water purity.

New approaches to research are needed to clarify basic concepts of environmental biology, i.e., the responses of living organisms to changing environments. Specialists in human biology should collaborate with microbiologists, botanists and zoologists for this purpose. Contamination of the water or soil environment of many other organisms with new chemical pollutants leads to an ecological disturbance in nature; observation of these effects is important for the understanding of human environmental biology.

2. RECENT TRENDS IN ENVIRONMENTAL POLLUTION

There can be little doubt that pollution of man's environment is increasing. Direct estimates of the amount of chemical pollutants in the environment at present cannot be given, but some idea of the magnitude of the problem may be gained from the fact that in Western Europe the total production of chemicals increased more than two-fold in the eight-year period 1953-60. Moreover, during that time the production of the chemicals of interest in the present context rose even more steeply: the output of petrochemicals increased eight-fold, that of plastics almost four-fold, and that of pharmaceuticals almost three-fold. Increases in the USA were four-fold for plastics, about three-fold for synthetic detergents and a little more than three-fold for pesticides. An important feature is the rapid increase in the production of insecticides in the USA; no comparable figures can be derived from available European reports. Western European countries, however, do record a total production of synthetic detergents in 1960 and 1961 that approaches the rate of increase and the total production for these years in the USA.

Not all of these increases would affect the respective environments. There were exchanges of chemicals between the two continents and

exports to other parts of the world. Nevertheless, it is obvious that among the great changes of the past decade, the production of chemicals — and in particular of synthetic organic chemicals — is important. There is, therefore, good reason for considering the possible impact of these chemicals on man and his environment.

Air pollution by smoke is declining in developed countries as a result of increased efficiency of combustion and the substitution of oil or natural gas for coal, whereas concentrations of some of the newer pollutants, such as those from motor vehicles, are increasing. In developing countries, where rapid industrialization and urbanization are leading to an increased use of fuels, combustion equipment and industrial chemicals, a concomitantly rapid growth of pollution problems may be expected.

With the great increase in the use of motor vehicles, problems caused by pollution from exhausts have arisen in many major cities. The unexpected and complex problem of photochemical pollution, first noted in Los Angeles, has been observed in other cities that have a high concentration of motor vehicles, stagnant air, and sufficiently intense radiation of short wavelengths to promote photochemical reactions.

The pollutants primarily emitted by motor vehicles — hydrocarbon vapours and nitric oxide — are not harmful at the concentrations normally found in town air unless they take part in photochemical reactions. Nitric oxide in low concentrations is slowly oxidized in the ambient air to nitrogen dioxide, but the reaction occurs more rapidly in the presence of hydrocarbon vapours. The risks to health from nitrogen dioxide are greater than those from equivalent concentrations of nitric oxide, but more work is needed to determine the concentration at which nitrogen dioxide affects the lungs.

Two other pollutants emitted by motor vehicles, carbon monoxide and lead, are also of concern, although they take no part in photochemical pollution reactions. Carbon monoxide combines reversibly (with a biological half-life of the order of three hours) with the haemoglobin in the body and prevents oxygen transport. In many cities pollution by exhaust gases is sufficient to inactivate 1%–6% of the haemoglobin in all members of the exposed population. Inorganic lead is emitted from the breakdown of tetraethyllead, which is used as a motor-fuel additive.

In some developed countries legislation has been introduced regulating the discharge of industrial wastes to sewers and watercourses, but many developing countries undergoing rapid technical development lack adequate numbers of trained personnel, equipment and other facilities for the assessment and control of environmental pollution.

VEHICLES OF TRANSFER OF POLLUTION TO MAN

Although it is artificial to draw a distinction between polluting substances reaching man by way of air, water or food — since, for example, a single chemical sprayed on a crop may be inhaled, may alight directly on the skin or conjunctivae, may be washed into a watercourse and subsequently drunk, or may be ingested in the sprayed crops or in fish that have been present in the watercourse — it is convenient to make such a distinction for purposes of description. Most environmental pollutants, however, commonly reach man by one of these vehicles rather than the others, and they will be considered separately here.

3. AIR POLLUTION

PURPOSES OF AIR-POLLUTION INVESTIGATIONS

Sources of pollution

Although each air pollution problem must be evaluated on the basis of its own individual characteristics, sources of pollution, in a general sense, may be classified into several broad categories: the combustion of coal and oil in domestic and industrial heating and steam-generating plants, emissions from motor vehicles, industrial effluents, and miscellaneous commercial and community activities such as the burning of solid wastes, solvent losses, pesticides and agricultural chemicals.

Preliminary assessment of a problem

Before complex methods are used to measure the concentration of pollutants, the nature and magnitude of the problem must be assessed. Many pollutants are invisible and odourless, and some can be very dangerous. Nevertheless, for the preliminary assessment of a possible problem, a careful inquiry about local sources, including fuel, suspected effects, inspection of the buildings and crops in the area, observation of smoke plumes and the use of the sense of smell may be of great value. These procedures may not, however, provide assurance that there

is no pollution problem, not only because some pollutants produce no effects detectable by sight or smell, but also because concentrations and reactions may be influenced by unusual meteorological conditions not present during the preliminary assessment. At this early stage of an investigation, the concentration of a gross and easily measured pollutant may often be taken as an indicator of the amount of some other pollutant, the estimation of which is more difficult or expensive to carry out; for example, if the main pollutant is coal smoke the assessment of smoke may give a rough indication of the concentration of polycyclic hydrocarbons.

Identification of sources of pollutants

Surveys involving the measurement of the concentrations of individual pollutants may be needed in order to identify unequivocally the sources responsible. These problems may be difficult; an example is that of distinguishing between the contributions made by coal combustion and those of motor vehicles. Here both sources may emit polycyclic hydrocarbons and carbon monoxide, and care must be taken to select for measurement indicator pollutants emitted from one or other source alone, for example, by calculating the ratios of concentrations of individual hydrocarbons by which the source may be identified.

Assessment of effects on health

Public health authorities in many parts of the world use measurements of air pollution to assess the magnitude of their problems in comparison with those in other areas. For this purpose a network of sampling stations may be established and observations made at fixed intervals for prolonged periods. In some surveys, intermittent sampling at different sites is used according to a predetermined statistical design, but whatever the procedure adopted it should be capable of yielding a reasonable estimate of the distribution of pollution exposures affecting the population within the survey areas and of demonstrating the variations that occur with the seasons and with atmospheric conditions.

Maximum values may be more relevant than mean concentrations, especially in studies of the acute effects of pollution; for this purpose observations must be made over periods of not more than 24 hours, and continuous or hourly records may be valuable. In studies of the development of chronic diseases and of long-term effects it is necessary to use in addition mean long-term concentrations of pollution. A

relatively simple sampling procedure has sometimes been used in which material is collected continuously over periods of a month or more at a time.

Exposure of individuals or population groups to specified pollutants is usually estimated from the results obtained with fixed samplers placed in the areas where people live or work. This procedure is usually satisfactory in urban environments where the concentrations of pollutants do not fluctuate very rapidly with time or place, but in some cases "personal" samplers may be required to obtain a satisfactory measure of the exposure of individuals, especially in their homes.

It must be recognized that health may be affected indirectly by impairment of well-being. For example, particles big enough to be deposited rapidly and too big to be inhaled and cause pulmonary disease may cause eye injuries, or may soil fabrics, buildings and paintwork, thus indirectly affecting health by causing annoyance; bad smells and eye irritation may not cause demonstrable pathological changes, but they affect well-being to a marked extent.

Assessment of the relation of weather to pollution

Frequent and widespread measurements of pollution may be needed in order to assess the effects of atmospheric conditions on the dispersion of pollutants or the chemical interaction of individual contaminants. Probably the most notorious examples of this type of problem are the Los Angeles photochemical pollution and the British smoke-polluted fog. In both instances reactions that occur between pollutants are greatly dependent on meteorological factors, and only by careful measurement can the mechanisms by which secondary pollutants are formed be elucidated.

Assessment of the effects of control measures

In many parts of the world, air pollution is regarded as an intolerable nuisance and measures to abate it have been taken. Obviously the effect of the implementation of "clean air" regulations can be assessed only by studying the results of measurements made systematically over a long period and in many places. All too often, use is made of short series of measurements to assess the effect of control measures; since pollution is so often dependent upon meteorological variability, care must be taken to ensure that no false conclusions are reached by careless interpretation of such measurements.

Use of measurements of pollution for planning and economic developments

If pollution of the air is to be avoided rather than abated, plans must be made so that power stations, industrial plants and domestic sources of pollution do not "overload" the air. In many parts of the world careful surveys of concentrations of pollutants are made before places are developed for industrial use or as areas of high population density. This practice has much to commend it, and the development of many pollution problems is avoided by the recognition of the importance of air pollution in town planning.

Development of air-quality criteria or guides

People may wish health agencies to state what they consider to be tolerable or intolerable concentrations of pollutants and to draw up regulations under which these limits may not be exceeded. WHO is attempting to establish such criteria and guides, along lines recommended by the WHO Expert Committee on Atmospheric Pollutants.[1] The need for widespread and frequent measurements of individual pollutants and combinations of pollutants for this purpose is obvious.

Measurement of pollution for research purposes

Seldom, if ever, is pollution simple; compounds often react in the air after emission. The structure and size of particles and droplets may be complex and may vary with temperature and humidity. Research into these matters is in its infancy and many measurements of many pollutants will be needed in order to determine the changing nature of pollution.

SAMPLING PRINCIPLES AND PROCEDURES

In regard to air pollution, "sampling" means the collection of a certain volume of air or a certain quantity of one or more pollutants for the purpose of determining the atmospheric concentration of pollutants.

Sampling usually precedes analysis and there may be a time interval of some length between the two operations. However, when it is desired to start a study of air pollution and it has been decided that the survey should concentrate on specified pollutants, a list of the analytical methods

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[1] *Wld Hlth Org. techn. Rep. Ser.*, 1963, No. 271.

available, together with the corresponding sampling method or methods, should be drawn up. By matching analytical and sampling methods to the needs of a study, the basis for a definitive choice is obtained.

Principles for the selection of a sampling method

The choice of technique depends on many factors: on the purpose of the measurements, on the type of effect being studied, on the appropriate period for averaging, and on the method of reporting results. Another factor is the limitations that are imposed by the sensitivity and specificity of analytical techniques.

Important considerations are that the sampling method should be simple and should produce a large quantity of useful data, and that the apparatus should be strong, cheap, portable and compact, and should preferably not require any source of energy at the sampling point.

Finally, it must not be forgotten that the sampling method should obviate any loss of the pollutant at the moment of collection and any transformation thereafter by mutual reaction of antagonistic pollutants or by disappearance of a pollutant as a result of adsorption, volatilization, agglomeration or shattering of the particles. It should provide a sample representative of the air as inhaled at the sampling point.

Sampling procedures

As regards duration of sampling period, two techniques are currently employed: (*a*) short-period or "spot" sampling and (*b*) continuous sampling for the measurement of maximum and average concentrations over definite time intervals. Spot samples are usually collected for specific purposes over periods of less than 30 minutes to several hours. Such samples have restricted value except where only minor changes in concentrations at particular periods of the day occur as a result, say, of the traffic density or where spot sampling is conducted to make random checks on pollution at many points. In general, pollution levels fluctuate widely in accordance with prevailing meteorological conditions and are influenced by such factors as the topography, mass-emission rates, temperature, velocity and density of stack gas, height of stacks, distribution of sources and distance from sources down-wind. It is obvious, therefore, that spot sampling cannot be employed to characterize fully the nature and magnitude of an air-pollution problem. The determination of maximum concentrations of a pollutant over short intervals is limited by the time-constant of the sampling or continuous recording instrument.

Systematic studies of the nature and extent of pollution in the ambient air to obtain data for epidemiological surveys, for evaluating the potential hazard to man, animals or vegetation, and for control programmes, usually require continuous sampling techniques. Maximum and average concentrations over definite time periods can be read or calculated, depending upon the duration of the sampling cycle. Within a given cycle, peak concentrations over relatively short periods can also be determined. The instrumental techniques, however, may lack specificity and the data must therefore be checked frequently by calibration and by other more specific analytical methods. Where continuous automatic instruments cannot be employed, the samples can still be collected continuously by appropriate chemical absorption or filtration of measured air volumes in a sequential fashion and analysed subsequently.

It is recommended that for international comparison of routine sampling measurements the period of collection should be standardized so that a short-term sample would be defined as one collected during 30 minutes and a long-term sample as one collected during 24 hours.

The physical and chemical properties of pollutants often influence the technique to be adopted. Thus, samples of gaseous pollutants can be collected in glass or metal vessels previously evacuated or in plastic bags inflated by a hand-pump or an electromechanical membrane pump; by aspirating air through a cold trap by which gaseous pollutants with a high boiling point are retained; by dissolving them in an appropriate solvent; by transformation, using an appropriate, and if possible selective, liquid reagent, into a compound that is easier to titrate or detect colorimetrically; by adsorption on a suitable solid adsorbent, possibly at low temperature, the pollutant being liberated by subsequent treatment; or by reaction with a solid reagent spread over an inert surface in a detector tube or on filter-paper. In the latter instance the reagent chosen should be such that the pollutant to be determined causes a change in colour, which can be used directly for measurement.

For liquid or solid pollutants, the following methods may be used: aspiration through a filter of known porosity, which retains ordinary and radioactive suspended matter; impaction of particles hurled at high velocity against a solid partition, in the presence or absence of a liquid; cyclone centrifugation, by means of which suspended matter of relatively large diameter is retained, possibly followed by filtration to remove small particles which the cyclone has not stopped; and thermal or electrostatic precipitation.

The various procedures have their advantages and drawbacks, which must also influence the choice of the sampling technique.

Sampling methods for direct analysis call for equipment that is generally expensive and must be set up for use at a single sampling

site. Consequently, the number of sites cannot be multiplied without increasing the amount of equipment and thus the costs involved. On the other hand, by means of direct analysis the daily trend of pollution at a given place can be determined. The method is especially valuable when it gives, either directly or by integration, a series of mean values over a given time interval.

Sampling methods for delayed analysis have the advantage that a large number of sampling sites can be kept under surveillance with only one expensive analytical installation. On the other hand, sampling is almost instantaneous at each site, and the results cannot therefore be compared with those from samples taken over a longer period. Furthermore, surveillance of a large number of sampling sites poses the problem of the division of the area concerned into units and of the most suitable way and time of visiting each of the sites chosen in these units.

MEASUREMENT OF AIR POLLUTION

Air-pollution nomenclature

The need for agreement on the use of well-defined and precise terms to describe phenomena connected with air pollution in different parts of the world has been pointed out by a WHO Expert Committee on Atmospheric Pollutants.[1] At present, the use in technical literature of imprecise words such as "smog", "smaze" and many others to describe the nature, origin and constitution of air pollution and the influence of associated atmospheric or meteorological factors creates confusion.

Units

The interchange of the results of investigations of air quality would be made easier if a common nomenclature, consistent units, and uniform methods were adopted internationally. A brief review of the problem was made at the 1963 WHO Inter-Regional Symposium on Criteria for Air Quality and Methods of Measurement and its conclusions were endorsed shortly afterwards by a WHO Expert Committee on Atmospheric Pollutants.[1] Recommended units for the expression of the results of sampling and the analysis of particulate and gaseous contaminants and of related environmental factors are shown in Table 1.

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[1] *Wld Hlth Org. techn. Rep. Ser.*, 1964, No. 271.

TABLE 1.   RECOMMENDED UNITS FOR AIR SAMPLING AND ANALYSIS

Item	Recommended units	Alternative or derived units
Particulate contaminants (liquid or solid) of known composition	milligrams per cubic metre (mg/m^3)	micrograms per cubic metre ($\mu g/m^3$)
Suspended or airborne particulate matter	miligrams per cubic metre (mg/m^3)	micrograms per cubic metre ($\mu g/m^3$)
Gases or vapours	milligrams per cubic metre (mg/m^3)	micrograms per cubic metre ($\mu g/m^3$) [a, b]
Gas volumes	cubic metres (m^3) at standard conditions [b]	
volume emission rates	cubic metres per second (m^3/s)	
Mass emission rates	kilograms per second (kg/s)	grams per second (g/s)
Velocity	metres per second (m/s)	
Air sampling rates	cubic metres per minute (m^3/min) or cubic centimetres per minute (cm^3/min)	litres per minute (litres/min)
Temperature	degrees Celsius (°C)	
Pressure	millibars (mb) or millimetres of mercury (mm Hg)	
Visibility	kilometres (km)	
Light transmission	percentage transmittance (%T)	
Light reflection	percentage reflectance (%R)	
Particle size	microns (μ)(10^{-6}m)	
Wavelength of light	millimicrons (mμ) (10^{-9}m)	ångströms (Å)(10^{-10}m)

NOTE. Time of day should be specified in terms of the 24-hour clock, e.g., 15.00 hours, not 3 p.m.

[a] ppm may be used as an additional unit of concentration but the original results should always be expressed in mg/m^3 or $\mu g/m^3$ as well; ppm by volume multiplied by $\dfrac{\text{molecular weight} \times 10^6}{22\ 400}$ yields $\mu g/m^3$ at standard conditions.

[b] "Standard conditions" means 0°C and standard pressure, i.e., 760 mm Hg or 1013.25 millbars.

The kilogramme–metre-second–ampere system should be employed for expressing the results of air-pollution measurements. The concentration of pollutants in terms of this system should be reported as mass per unit volume at a standard or reference temperature and pressure. There is general agreement that the standard pressure of 1013.25 millibars (760 mm Hg) and temperature of 0°C should be employed. Although in many instances the correction to standard or reference gas conditions may not be justified for local purposes because of inherent errors or limited accuracy of measurements, it is essential that the temperature and pressure conditions should be reported for all measurements involving comparative or precise studies. Normally, the concentration of air pollutants in this system should be expressed in milligrams per cubic metre.

Some substances occur in the air in such low concentrations that the recommended mass concentration unit (mg/m^3) is greater by a factor of 1000 or more than the mass actually present in a cubic metre of air. Polycyclic aromatic hydrocarbons and analogues, potentially carcinogenic, as well as some highly toxic compounds, are in this category. In such instances, the concentration may be expressed as micrograms (μg), nanograms (ng) or picograms (pg) per cubic metre.

Computation of the results of atmosphere sampling and analysis would be simplified considerably and the data rendered more easily available for comparison if the units recommended in Table 1 were adopted. It will be noted that for many items listed in this table alternative or derived units are given along with the recommended units. The choice is one of convenience in reporting data, mainly to avoid the use of cumbersome decimals.

ANALYTICAL METHODS

An extensive review has been made of many of the analytical methods now in use.[1] Further research is, however, required into analytical methods.

Background

Analytical methods for measuring air pollution range from very simple chemical techniques to highly complex procedures using elaborate instruments. The type and number of analyses that may be required depend on the purposes of the study. A simple standard analysis may be

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[1] Katz, M., *Measurement of air pollutants: Guide to the selection of methods* (in preparation).

repeated thousands of times and need many man-hours. On the other hand, the analysis of a single sample may require the efforts of a research team for a number of days or weeks.

Simple methods

One of the goals of research into the development of analytical methods is to provide simpler techniques, not only to reduce the time taken for analyses but also to allow their use over a wide range of locations, both field and laboratory, by personnel ranging from un-qualified voluntary co-operative workers to trained chemists. Simple methods are particularly desirable for the common pollutants measured routinely in network operations or extensive long-period field studies.

Sensitive methods

Many existing or potentially useful methods for studying air pollution are insensitive; this is particularly true of many methods used in industrial hygiene. To overcome this deficiency, more elaborate sampling equipment, or additional time and equipment for analysis in the laboratory, may be required. While sensitivity (ability to detect small amounts) is very important in air-pollution studies, an accuracy of $\pm$ 20 % is usually sufficient.

At present, methods that are both simple and sensitive are lacking, particularly for use in the field. For more complex studies, e.g., the determination of ions or compounds by size classification, particularly in the sub-micron size range, the need for sensitivity is paramount.

Specific methods

Air pollutants of interest are usually present in small quantities, often together with other substances. These additional substances pose problems if they interfere with the analytical methods used for a pollutant of special interest. Many analytical methods have not been investigated in sufficient detail to enable us to discern the nature and extent of the interference that may occur in analysing polluted atmospheres, or how to overcome it or correct for it.

Organic pollutants

New substances from the chemical and metallurgical industries continually pollute the air. Studies of the effects of new organic pollutants

would be facilitated by the development of sensitive and specific methods for their identification and measurement. This may require a substantial effort and expenditure of funds.

Gas-aerosol relationships

The role of particulate matter in the possible potentiation of effects of gases on the respiratory system needs extensive investigation and clarification. Current techniques are grossly inadequate for an understanding of the absorption–adsorption relationships between common gaseous pollutants and particulate air pollutants and their subsequent elution in the respiratory system. The solution of this problem may require the use of advanced physical techniques and chemical analytical methods.

Chemistry of the sulfur cycle

The chemistry of the sulfur cycle in the atmosphere is of widespread interest, because sulfates may potentiate the effects of sulfur dioxide. Methods of determining the fate of sulfur compounds in the atmosphere are needed, particularly in the sulfur dioxide to sulfur trioxide to sulfate conversion. Other sulfur-containing compounds of interest include inorganic and organic sulfides, thiols (mercaptans) and sulfites.

Photochemistry

The combustion of fossil fuels, including the operation of motor vehicles, is an important source of atmospheric pollution. In order to extend our knowledge of the effects of pollutants from these sources, studies are needed to define more precisely atmospheric photochemical reactions involving organic compounds. The development of analytical methods is an integral part of such studies.

Tracers for meteorological research

A limitation on the use of tracers for atmospheric circulation studies, particularly over long distances and for extensive time periods, is the lack of non-toxic tracer materials that are stable over the normal range of the ambient air temperature, humidity, solar radiation, and precipitation. Of greatest promise in this search are polar compounds capable of being detected in very minute tracers by gas–liquid chromatography with electron-capture detection.

Recent developments in analytical chemistry

During the past 10 years, developments in analytical chemistry have provided unusual opportunities for greater sensitivity and specificity in air-pollution measurements. Gravimetric and titrimetric methods have been supplemented to an increasing degree by spectrophotometry, infrared spectrometry, coulometry, gas–liquid chromatography and other techniques. These newer methods are already widely used. It is important that air-pollution studies be conducted with the best analytical methods available and that special attention be paid to the purity of the reagents used. The simplicity, sensitivity, reliability and economy of many of the newer methods should result in significant advances in the study of air pollution. It is important to recognize that the high cost of certain new equipment may be justified by the results obtained and the savings in manpowei costs.

Organic pollutants can now be identified and determined in a most efficient manner through the use of gas–liquid and other types of chromatography. A few years ago, only a limited number of organic compounds could be determined. Hydrocarbon indices could be measured on a non-discriminatory basis. With the introduction of gas-liquid chromatography, the constituents of complex mixtures of gaseous organic compounds can be separated and individual constituents identified and determined. With programmed-temperature and similar types of chromatography, organic particulates of high molecular weight can be analysed.

Infrared spectrophotometry by itself, or after chromatographic separation, has proved useful for the study of certain air-pollution problems. Infrared methods may be used not only in the identification and estimation of organic pollutants for research, but also in monitoring systems, e.g., for carbon monoxide.

In special circumstances, thin-layer chromatography, mass spectrometry, fluorimetry, phosphorimetry and polarography can be used in the study of air-pollution problems. These techniques are at present used only occasionally for routine measurement, but they are important as research methods for special problems. For example, complex mixtures of hydrocarbons may be difficult to analyse by gas–liquid chromatography alone. Thin-layer chromatography can then be used as an initial step in which preliminary separations are obtained, and the separated components can then be injected into a gas chromatograph for final separation, identification and estimation. Likewise, mass spectrometry can be used to identify materials that have been separated chromatographically. Fluorimetry is often used, particularly in conjunction with special observations made at very low temperatures. Likewise,

phosphorimetry provides a powerful means for making identifications and determinations when only minute amounts of material are available.

The study of inorganic pollutants is now made easier by the availability of new techniques, including new reagents and new instruments. One of the older analytical methods, flame photometry, is being more widely used than in the past because of new methods of excitation. Originally the flame photometer was used only in determining alkali metals or alkaline-earth metals. Better methods of excitation have made it possible to use flame photometry for other determinations, such as the estimation of magnesium, zinc and lead. The technique is remarkably sensitive and is reliable, particularly when interference effects are not serious.

Of special significance is the recent introduction of atomic absorption spectroscopy. This technique is generally as sensitive as, or more sensitive than, either flame photometry or emission spectroscopy. More important than its sensitivity is the fact that atomic absorption spectroscopy is inherently specific. The technique is simple and the equipment relatively inexpensive, at least when compared with that required for emission spectroscopy. The atomic absorption of radiant energy by atoms in the ground state serves as a means of identification comparable to the emission of radiant energy by atoms in excited states. Absorption serves as a means for the quantitative estimation of minute amounts of metals.

The recent development of specific, selective and sensitive reagents or reactions has made possible the detection and determination of many substances of interest in air-pollution work. The great sensitivity inherent in the use of many of the reactions permits determinations to be made in the microgram and nanogram range. Specific or highly selective reactions enable direct measurements of pollutants to be made, often without any need for concern regarding possible interference. Spectrophotometric equipment, upon which many of these tests depend, is fortunately becoming widely available.

The recently developed ring-oven methods offer certain advantages over spectrophotometric techniques, particularly for the analysis of relatively small samples collected over a short period. The ring-oven is a simple, inexpensive apparatus which permits separation, concentration and use of chemical means for the detection and determination of various substances at microgram and nanogram levels. Ring-oven methods offer great promise for the study of airborne particulates because they are sensitive, reliable and convenient. Results can be obtained in which the relative errors are not more than 5%–10%, which is usually acceptable at microgram levels. Specific methods are already available for the determination of aluminium, beryllium, nickel,

copper, iron, zinc, lead, cadmium, vanadium, antimony, selenium, phosphate, and sulfate. Additional methods are being developed.

Miscellaneous methods

Neutron activation is sometimes used where extremely minute amounts of material must be studied. This technique provides great sensitivity and reliability and is sometimes the only method applicable.

X-ray spectrometry sometimes provides special information and may be used as an adjunct to microscope studies. Microprobe methods are particularly attractive for studying airborne particulates in special cases. Highly skilled technicians are required and the equipment is very expensive. The same comments apply to electron microscopy, which is useful in the investigation of special problems.

Certain electrochemical methods have special applications in air-pollution work. Coulometric titrations may be used where very sensitive and accurate methods are required. These methods are particularly attractive for continuous monitoring of air pollutants.

Recently, automatic instruments have become available that are sufficiently sensitive for atmospheric measurements. These employ standard techniques, such as colorimetry, conductivity, fluorescence quenching, and absorption spectroscopy.

BIOLOGICAL EFFECTS AS INDICATORS OF POLLUTION

Biological indicator systems have been of very great importance in indicating the harmfulness of pollution to human well-being. Effects on vegetation (for example, of sulfur dioxide on alfalfa or lichens, of fluorides on gladioli, or of ethylene on the flower of the tomato plant) are specific and semi-quantitative, though an experienced plant pathologist may be required to differentiate the effects of pollution from those of plant diseases, climatic changes, or soil conditions. The effects of photochemical air pollutants on annual blue grass (*Poa annua*) and pinto bean (*Phaseolus vulgaris*) have been used to detect and estimate ozone and peroxyacetyl nitrate in mixtures. In addition, biochemical studies on plants help in the study of the effect of pollutants on human biochemistry.

Man is, however, the ultimate biological indicator of air-pollution hazards, and for at least one pollutant, carbon monoxide, the human body acts as an integrating sampler. The direct absorption of this pollutant into the blood from the lungs and the reasonably well-defined uptake and excretion rates permit the amount of carbon monoxide

in the blood of non-smokers to be used as an index of exposure within the previous 4-8 hours and as a numerical guide to the health hazard. By measuring accurately the amount of carbon monoxide in equilibrated expired air of exposed persons, the health hazard can be determined directly and simply with less difficulty than if the same measurement were made in the ambient air.

Serum cholinesterase depression is another valid biological indicator of human exposure to organic phosphorus insecticides, which sometimes become general air pollutants when sprayed from aircraft.

CHOICE OF DEVICES AND INSTRUMENTS

Many devices and instruments are available for the study of air pollution. They range from simple apparatus for the identification of a pollutant to elaborate instruments and techniques for the quantitative measurement of specific substances. The choice of the method depends on the purpose of the measurements (as discussed previously) and, in addition, on a number of practical considerations related to the availability of manpower, money and supporting facilities.

Nature of the problem

The specific requirements of the investigation will for the most part dictate the equipment to be used. For example, simple tests using impregnated papers or detector tubes, or in some cases merely an inspection of the area, may suffice to establish that an air-pollution problem does exist. The simplest and most economical method adequate for the task should be selected, unless there are specific reasons for doing otherwise. On the other hand, preliminary investigations may reveal the need for additional studies varying in scope from simple short-term surveys to extensive long-period investigations. As the complexity of the investigation increases, the choice of devices and instruments that may be used is limited by a number of general considerations. These are summarized below.

(a) Cost. A limiting factor in most investigations is the money available. It is imperative that the money allocated for measuring devices and instruments balance that allocated for data analysis and interpretation. Too often in the past an unrealistic portion of the budget has been used for the collection of data, with the result that the findings were never satisfactorily interpreted, analysed or reported. In most studies the limitation of funds will force a compromise between what is desirable and what is possible. However, no compromises should jeopardize the basic purposes of the project.

(b) *Availability.* Ready availability of appropriate equipment is an important consideration in the selection of apparatus. "Shelf items" are preferable when available, particularly because they are readily serviced and replaced. However, apparatus may in some cases have to be built specially.

(c) *Sensitivity and specificity requirements.* The need to select a device with sufficient sensitivity and specificity for the needs of the project is self-evident. On the other hand, the selection of equipment that is more sensitive or more accurate than necessary should be avoided, not only because it will cost more but also because it may need more attention and maintenance.

(d) *Sampling-time requirements.* The determination of the sampling-time requirements of the project is extremely important and is related to cost. In general, the method of measurement should provide data to suit the sampling time required. Automatic instruments should not be used when simple equipment would suffice. The folly of selecting complex equipment in circumstances where it is not needed lies not only in the production of data that are never used but also in increased costs for their analysis and for calibration, servicing and maintenance of equipment. In many circumstances the selection of a single monitoring station equipped with continuous automatic instruments and with outlying satellite stations with simple devices may produce more information on the distribution and variation of pollutants than a number of automatic stations at the same or greater total cost.

(e) *Data output.* In certain circumstances it may be desirable to equip automatic instruments with a direct digital read-out or a tape output for automatic data processing. However, a tape output is perhaps inadvisable except where very short averaging periods of, say, less than 30 minutes are used. It should be pointed out that a number of steps are required for handling data between a tape output and the computer data-analysis programme. These consist of the production of additional tapes based on information in the operator's log for corrections, such as omission of calibration and instrument malfunction periods, instrument drift, etc. The validity of instrument output needs to be checked, preferably by automatic methods. The dependability of automatic instruments and data-output systems at present is such that tape output should be added only if it is essential.

(f) *Servicing requirements.* Instruments should be reliable enough to operate unattended for long periods. This requirement must be balanced against the availability of technical manpower to service and maintain

equipment. The extent and frequency of calibration needed may also affect the choice of equipment for a particular project.

(g) *Portability, housing and power requirements.* In some cases the choice of equipment is dictated by the need to use the same instrument at several sites, in which case portability is a dominant requirement. Availability of housing and of a stable power supply must also be considered.

Instruments for sampling particulate pollution

In addition to the general requirements discussed above, the selection of equipment for sampling and analysis of particulate pollution is influenced by the specific needs of the project. Sampling equipment may be very simple or very complex and analytical techniques also vary in complexity. Types of sampling and subsequent analysis may be classified as follows:

(a) *Suspended particulate matter.* Particulate matter small enough to remain suspended in the air is collected by filtration, impaction, electrostatic precipitation or thermal precipitation. Analysis may be made in terms of soiling, total mass, total mass of specific chemical components, total count, count by size fractions, or chemical composition by size fractions; other separations may be based on differences in physical properties. Sampling equipment ranges in complexity from simple filtration devices to elaborate size-classification apparatus. Analytical techniques range from macro-methods for estimating the total weight of particles to micro-methods for identification of constituents in different size classifications. The latter methods are especially important when dealing with particles in the sub-micron size ranges.

(b) *Settleable dust.* Dust that settles out of the air, and that generally comprises particles greater than 10 microns in diameter, is collected in a suitable container over long periods, and analyses are made to estimate the total weight or the weight of some specific component.

(c) *Emissions.* Particles in emissions may be collected from conduit systems or stacks, preferably isokinetically, using techniques that will depend on the size distribution of the particles and on the humidity and temperature.

Gases and vapours

Samples of gases and vapours can be collected by employing several physical and chemical principles. Analyses can be made by determination

of the mass of specific components or of general classes of components. The analytical techniques that can be used range from relatively simple standard chemical methods to advanced techniques such as chromatography can be used in conjunction with other methods, such as mass spectrometry and spectrophotometric analysis.

Of special interest for the identification and detection of gases and vapours is the use of simple devices such as indicator or detector tubes and test papers. These are particularly useful for the initial assessment of air-pollution problems, although they may also be used in many other types of air-pollution investigation.

Indirect methods

Analyses of pollutants or of the effects produced by them can be made by using natural or generated electromagnetic radiation or by acoustical techniques. Methods of this type range from simple smoke-density evaluations using the Ringelmann chart to advanced techniques now under development that utilize recently discovered physical principles or improved physical techniques. Included in the latter group are the use of passive infrared radiation for semi-quantitative chemical measurement of plume constituents, infrared radiation from atmospheric oxygen to make temperature soundings, and laser or radar beam backscatter for inversion-height determination. Techniques measuring the effects of pollutants include the use of corrosion panels and examination of the fading and soiling of fabrics.

Meteorological measurements

Since meteorological conditions have an important effect on air pollution, meteorological equipment may be needed in some studies.

Ancillary equipment

Various types of miscellaneous equipment or services are required in air-pollution studies, such as pumps, flow meters, housing for equipment, power supplies and data read-out systems. The mass production and standardization of such devices would be very helpful.

Reporting of results

For the purposes of general assessment, it is desirable to report whether or not a pollutant is present and, if so, in what approximate

amount in a specified number of samples for specified times, weather conditions and places. The immediate results may be presented in the form of a list of pollutant concentrations present in the samples obtained. If large numbers of samples are analysed, charts, histograms or cumulative frequency distributions are useful.

For the identification of sources of pollutants, reports of results should make it simple to determine the gradient in time and space between source and sampling site under specified weather conditions, especially wind direction and speed. As long as this requirement is met, averaged data are usually satisfactory. However, if the source strength varies with time, the times of sampling will be of great importance and should be reported.

For the assessment of effects on health, a wide variety of reporting methods are used. Since some pollutants are thought to produce acute effects on health by short exposures, hourly or half-hourly average data or continuous measurements are desirable. Such measurements yield very large amounts of data, for whose interpretation methods of reporting and data reduction are of great importance. The information that is usually desired is the number of events and their duration or the proportion of time during which a specified level of pollution has been exceeded. For example: (a) the number of times a year (or month) that 0.6. mg/m^3 of SO_2 has been exceeded, (b) the length of time during which this level was exceeded on each occasion, and (c) the proportion of the measuring period during which it was exceeded

For some pollutants, such as carbon monoxide, the effect on people is related to an exposure long enough to lead to an accumulation of the material in the body. For this pollutant, four- or eight-hour averages are particularly important but, as above, the number and duration of events and the proportion of the sampling period for which certain levels have been exceeded is desirable. Finally, for some pollutants, e.g., lead, only long-term average exposure is of medical interest. For the evaluation of other effects, the reporting should depend on the source and its effect.

For the assessment of control measures applied to large or complex sources, long-term trends using highly reproducible methods and the reporting of median or average data for several years would be useful or, if the control measure is applied to a source point, reports will be needed comparing measurements before and after the introduction of control.

For the assessment of the relation between weather and pollution, the reporting methods must depend on the specific hypotheses being tested, but mathematical models or selected data will often be desirable, and long-term averages are unsatisfactory.
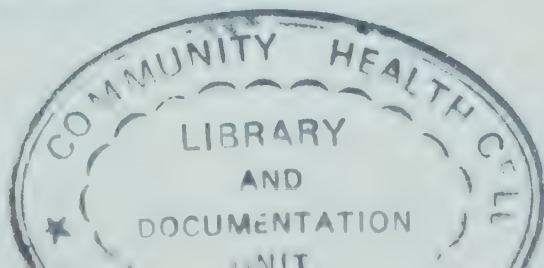
When continuous recording is used, maximum values are often reported with little attention to the dependence of maxima on the duration of sampling, the intrinsic averaging time of the instrument, or the prevailing weather conditions. Maxima tend to conceal analytical or measurement errors as well, and this is an additional reason why maxima, if reported, should be related to the underlying frequency distribution.

The following reporting methods are to be preferred:

(1) For a specified period of sampling or integration, the results can be grouped by frequency of occurrence and a chart drawn up to show this — or, preferably, a histogram prepared of the percentage frequency for, or exceeding, a certain concentration.

(2) A series of stratified histograms can be drawn for each site, for the whole duration of the study, or for selected periods such as a month, a week, all Mondays, or all Tuesdays. Or — e.g., in the study of pollution by motor vehicle exhaust gases — histograms showing data for successive hours of the day can be drawn, but once a certain hour has been selected, the scheme of results should cover, say, all Mondays, all Tuesdays, or all the days of the week.

(3) The above comments on histograms apply also to the averages of results, for in addition to the general average of all determinations, there can be monthly, weekly, daily and even hourly averages. The values averaged should be clearly specified.

(4) In every case the results should be presented with a view to their being used statistically; graphs or charts are often preferable to tables or figures.

(5) Another point of view that should not be neglected is the establishment of a pollution map for a certain region. The principles listed above are again valid as regards the periods of time to be considered. In addition, the use of isopleths (lines connecting points of equal pollution) should be attempted.

(6) Wherever possible, it is worth while to bring out the correlations in time or space with a pollution factor. Thus, curves showing the concentration of a given pollutant can be traced on the same time-scale as those showing the emissions of a pollutant source or wind speed and direction.

Meteorology and air-pollution measurements

Air-pollution measurements may be made for various reasons. In most cases, however, meteorological information should be utilized

in judging the significance of the results. The number and type of meteorological measurements will depend on the purpose and complexity of the study and on the availability of data and instruments. Data on temperature, humidity, wind speed and direction and precipitation are generally available through official governmental weather agencies. Data on temperature changes with altitude are often of particular use.

The carbon dioxide content may have significant consequences for the heat balance of the earth's atmosphere. Observations of certain pollutants may help in understanding atmospheric movement. Further, although thick fog is not caused exclusively by air pollution, the presence of pollutants may prolong poor visibility conditions.

Pollution, especially by particles, can also interfere with solar radiation. Where pollutants are examined for other reasons, e.g., in connexion with their influence on health, meteorological factors should be taken into account, as the concentration of pollutants depends on them as well as on the properties of the source. Both pollution and meteorological factors may have effects on health.

As long as only a listing of pollutants is aimed at, there may be no need for supplementary meteorological data, but they may be needed in interpreting the degree of contamination observed in the atmosphere.

The most important factors influencing the concentration of pollutants are wind (direction and speed) and atmospheric stability. As a rule it will not be possible, nor is it always necessary, to measure wind direction and wind speed in every place where pollution measurements are made. The need for such data depends on the purpose for which pollution is being measured.

The meteorological information available can be used with the greatest effectiveness if the time during which the pollutant is sampled is short — not much longer than, say, one or two hours. As a rule, one should proceed cautiously when correlating the averages or totals for the concentration of a pollutant determined over a long time, such as a month, with wind data, e.g., with the amount of time during which the wind has a specified direction. It could be that exposure to the pollutant occurs mostly when the wind has a relatively uncommon direction during the observation period.

The effect of atmospheric stability, depending on, among other factors, the vertical temperature distribution in the relevant layer, is complex. Stable conditions tend to suppress vertical motions in the atmosphere, but this suppression may have a different effect on pollutants originating from high-level sources than on those emitted into the atmosphere at low levels. In the first case (at least as long as there is some wind) the pollutant will not, or will rarely, reach the ground; in the second case it will not be diffused upwards. However, when

atmospheric stagnation is prolonged (e.g., a week or longer), mixing of pollutants may occur below elevated inversions.

It is difficult to obtain reliable information on the stability of the lower 200-300 m of the atmosphere. The best way to obtain this information is with meteorological towers, but these are not available in sufficient numbers. On land the stability is greatest during the early hours of the morning and least during the afternoon. It is strongly recommended, therefore, that if observations with a duration of about one hour can be made, this should not always be done at the same time of day, as otherwise a bias may be introduced into the analysis. Continuous or repeated measurements are to be preferred to demonstrate the diurnal variation of pollutants. Important meteorological factors are precipitation, which may have a cleaning effect, depending on the size of the droplets as well as on the properties of the pollutant, and solar radiation, which may give rise to chemical reactions. The latter phenomenon is more a chemical than a meteorological problem, but its existence indicates that it is not always possible to compare observations on special pollutants at different latitudes, altitudes and seasons. In such cases it may also be of importance to have information with respect to cloudiness.

The relative humidity may play a role, as certain pollutants, by virtue of their electrolyte content, can cause a deterioration in visibility, as was mentioned earlier. The presence in the air of aqueous fog droplets facilitates the oxidation of sulfur dioxide to sulfuric acid.

Reliable conclusions from air-pollution observations are therefore more likely to be drawn when air pollution and meteorological measurements are obtained in a co-ordinated manner. This co-ordination should, where possible, begin at the start of the activities, notably when planning the siting of the observation posts in order to make the observations as representative as possible.

The development or evaluation of mathematical models for the diffusion of pollutants from isolated point sources as well as from extended sources, such as cities, must be considered. It might also be useful if information with respect to the influence of topography on the diffusion of pollutants could be studied by means of mathematical models.

DANGER TO MAN OF CERTAIN AIR POLLUTANTS

Epidemiological studies indicate that in stagnant urban air concentrations of pollutants higher than normal but below catastrophic levels have perceptible and possibly cumulative effects on susceptible

people. Various indices of mortality and morbidity have been used, some of which are described briefly below, but obviously the effects of sub-acute pollution become more readily apparent when many susceptible individuals are studied. Hitherto, studies in the United Kingdom have failed to incriminate specifically and separately either smoke or sulfur dioxide — the pollutants commonly measured as indices of pollution. The implementation of the Clean Air Act in the United Kingdom is fortunately leading to the reduction of pollution by smoke, and further studies of responses to pollution in which the ratio of smoke to sulfur dioxide has altered may enable the separate roles of these two pollutants to be assessed.

Two diseases in the cause of which air pollution is thought to play a part, chronic bronchitis and lung cancer, are demonstrably closely linked to other factors, particularly cigarette smoking. The study of industrial populations — groups of men exposed in their occupation to high concentrations of pollutants suspected of influencing the development of the diseases mentioned above — is of substantial value. The results often discourage the acceptance of simple hypotheses involving irritants and classical carcinogens.

WHO has sponsored several pilot studies of pollution in pairs of European cities and its relation to the prevalence of lung cancer. The results indicate that this expensive and time-consuming technique is of very limited value, chiefly because no assessment of past exposure is possible. If urban environmental surveys are made, they should be related to prospective epidemiological studies.

Epidemiological studies using comparable methods of similarly employed populations in London, rural England, eastern cities in the USA, San Francisco and Los Angeles have shown that the persistence of cough and sputum is relatively common in all the cities studied and that cigarette smoking appears to be the major cause of this. Pulmonary function tests gave nearly identical results in the cities on the east and west coasts of the USA, but the results were lower in comparable groups from rural England and even lower in the London population. The frequency of combinations of persistent cough and sputum with shortness of breath or disabling acute respiratory illness was greatest in London, less common in rural England and least common in cities of the USA. These frequencies might possibly be related to the incidence of air pollution.

Many types of air pollution produce unpleasant odours but quantitative relationships between specific substances or combinations of substances and the responses of various populations need further study.

Irritation of the eyes and respiratory tract is the main symptom caused by photochemical pollution of the Los Angeles type. This has

been associated with oxidizing materials in the air. Whether this association will be found in other communities is not certain. This type of pollution appears to aggravate the symptoms of some persons with chronic respiratory conditions, but measurement of this effect has been difficult.

Atmospheric carbon monoxide levels sufficient to produce 2% carboxyhaemoglobin are relatively common in large cities having many automobiles. Carboxyhaemoglobin in the blood at a concentration of 2% has been shown to interfere with psychomotor functions but whether this can influence the ability to control a motor vehicle is a matter for investigation.

Ozone is known to be lethal to animals at concentrations of 6 ppm, which is only six times the maximum concentration recorded in Los Angeles. It was recently shown in 11 human subjects that exposure to 0.6 ppm for two hours interfered with the diffusion of gas from the alveoli to the blood. The means whereby such effects are produced and the factors, if any, that influence the sensitivity of different groups in the population need to be studied.

Some pollutants, such as lead, that are stored in the body, may produce toxic or other effects, depending on the amount so stored. No harmful effects have been observed due to lead in the ambient air, but further investigation is needed.

Pollution of industrial atmospheres by synthetic organic chemicals and their intermediates is common. The study of the effects produced and the determination of tolerable concentrations are the province of the toxicologist and the industrial hygienist. Outside the factory, contamination of the air by synthetic organic chemicals is expected to occur merely as a phase in the purposeful application of these substances to vegetation, soil, and surfaces of buildings and additionally in the storage of foods and in the household. The problems involved in this transient type of pollution are likely to be local in extent and, since the chemical concerned is already identified and its properties are known, precautions against its inhalation can be applied accordingly.

More general pollution of the atmosphere by synthetic organic chemicals is probably insignificant. (This hypothetical problem must certainly be regarded in the light of the very real contamination of the urban atmosphere by "traditional" and "newer" inorganic substances.) It is doubtful whether the synthetic pesticides, whether formulated as liquids or as powders, can easily be redispersed in inhalable form since their formulations and the methods by which they are dispersed are designed to produce maximum retention by the surfaces to which they are directed. Only considerable attrition could produce from

these applications particles that might again become airborne in sizes small enough to be inhaled.

Emissions of synthetic organic chemicals by industry are likely to be very small, since they are primary products and not wastes. Within the factory, most waste synthetic organic chemicals can be destroyed in the same way as odoriferous gases by feeding the air containing them into the stack, either through the fire-bed or at some point before the heat exchanger when the molecule in question may be completely disrupted. However, some synthetic organic compounds cannot be completely disrupted by burning. For instance, polyvinyl chloride liberates hydrogen chloride, polytetrafluoroethylene liberates hydrogen fluoride, and sulfur-containing compounds yield sulfur dioxide and sulfur trioxide. The destruction of scrap organic material such as waste plastics ought always to be complete and such material should never be burnt on open dumps.

There is good reason to deduce from investigations on the pollution of air by motor-vehicle exhausts that the ultimate fate of organic matter in the air may be complete oxidation. It is undeniable, however, that some compounds may take part in reactions by which irritant substances are formed as more or less long-lived intermediates.

Long-term dangers of air pollution

General air pollutants with demonstrated or potential health effects are listed in Table 2. Air pollutants occurring locally (e.g., arsenic, beryllium, and fluoride) are included because serious long-term health effects have occurred in man and animals living in communities adjacent to industries emitting these substances.

Among the sixteen air pollutants or air-pollutant groups, seven are thought to have potential chronic effects (column 2) at levels actually observed. On the other hand, most of the generally recognized air pollutants may, in appropriate combinations and at certain levels, become a potential threat to health (column 3). These conclusions are derived from toxicological studies on animals or man, experiments in industrial hygiene and epidemiological studies.

The high respiratory morbidity and mortality rates in urban areas of Europe and North America have led to the idea that the inhalation of polluted air has, among other things, led to chronic respiratory disease. However, the reported high incidence of chronic bronchitis in smaller towns and villages in Italy and Yugoslavia and the frequency of cor pulmonale in some rural areas in India suggest that factors other than urbanization and smoking may be involved.

TABLE 2. AIR POLLUTANTS WITH RECOGNIZED OR POTENTIAL LONG-TERM EFFECTS ON HEALTH AT USUAL AIR-POLLUTION LEVELS

Substances with known effects on health (acute or chronic)	Substances thought to have long-term effects per se [a]	Potential long-term effects of combinations
Arsenic	Arsenic (arsenical dermatitis)	
Asbestos	Asbestos (asbestosis, mesothelioma)	
Beryllium	Beryllium (berylliosis)	Be + F (fluorides potentiate pulmonary changes in berylliosis)
Carbon monoxide		Synergistic in pO_2 depression
Carcinogens		Carcinogens produce tumours in presence of promotors
Fluoride	Fluoride (fluorosis)	Fluoride (promotes or accelerates lung disease)
Hydrocarbons		HC + $O_3 \rightarrow$ tumorigen + influenza→cancer
Hydrogen sulfide (possibly with mercaptans)		Antagonizes pollutants (strictly speaking not detrimental to health)
Inorganic particulates	Inorganic particulates (pulmonary sclerosis)	
Lead		
Nitric oxide		
Nitrogen dioxide	Nitrogen dioxide (mild accelerator of lung tumours)	NO_2 + micro-organisms (pneumonia) + HNO_3 (bronchiolitis, fibrosa obliterans) + tars (smoker's lung cancer)
Organic oxidants (peroxyacylnitrates)		
Organic particulates (asthmagenic agents)	Asthmagenic agents (asthma)	
Ozone	Ozone (chronic lung changes, accelerated aging)	O_3 + micro-organisms (lung-tumour accelerator)
Sulfur dioxide, sulfur trioxide		SO_2, SO_3 + particulates aggravate lung disease

[a] Effects are given in parentheses.

The widespread acute and subacute respiratory tract irritation from the soot and sulfur dioxide type of pollution in Europe and from photochemical reaction products in Los Angeles has led to a supposition that long-term effects on the respiratory system may be occurring. Few studies of the relationship between acute and long-term effects have been made.

In a study of the long-term consequences of an acute exposure to pollutants in Donora in 1948, which caused an immediate rise in mortality, it was found that those who experienced immediate acute effects but who had no previous respiratory symptoms showed no increased mortality 10 years later.

Mechanisms of pollutant action and absorption by the respiratory tract, and methods of study

Mechanisms of long-term effects are not well understood. In particular, little is known about the relation of acute reaction patterns of the airway (calibre narrowing, secretion and cough) and long-term effects.

The respiratory tract, within which inhaled foreign material may come into intimate contact with the body's circulating blood, has a number of defences.

First there is the complex anatomy of the nasal cavity and upper respiratory tract, which causes larger and heavier particles to be deposited by impaction and settlement. Generally, particles of this size are similar to those that are deposited in dust-fall jars used for environmental sampling. Since these particles do not reach the deeper parts of the lung, their long-term effects are probably relatively unimportant; their main adverse effect on health is conjunctivitis through foreign-body reactions.

The smaller particles (less than about 3μ) usually pass through the upper respiratory tract to reach the deep parts of the lung. There they may be dissolved, if soluble, or ingested by phagocytes if insoluble. They are sometimes deposited peripherally, or filtered out by the lymph nodes. If the particles are one of the forms of quartz or some other minerals, or beryllium, they may ultimately lead to fibrosis or granulomatosis.

Thus it is particle size or, more precisely, the falling velocity of the particles that determines which part of the respiratory tract receives what dose and type of particulate pollution.

By contrast, it is solubility that determines which portion of the respiratory tract becomes the main target for gaseous pollutants. In high concentrations most of the inhaled sulfur dioxide is absorbed by the mucous membrane of the nose and upper respiratory tract, but as the concentration decreases a smaller fraction of the inhaled dose is absorbed by the airway.

Particulate pollutants (even if chemically inert) and gases such as sulfur dioxide are capable of causing changes in airway calibre measurable by their effects on resistance to airflow. It has been shown in

animals that inert particles of sodium chloride, which alone had little effect, could greatly augment the effect of sulfur dioxide on airway resistance. From this work have grown many additional studies of the effects of particle and gas combinations. Three general principles predominate. First, the particle surface is thought to be a place where gas molecules can react. An example is the oxidation of sulfur dioxide to sulfur trioxide, which is facilitated by the action of manganese in the dust. The second mechanism is the concentration of gas and liquids on a particulate surface. Thus, the local concentration of pollutant molecules where a particle impinges on the surface of an airway or alveolus may be much higher than the average predicted from the assumption that the pollutant molecules would be uniformly distributed throughout the inhaled air. The third mechanism is the ability of particles to carry pollutant molecules where they might not otherwise be carried. For example, it has been shown that fine soot particles will bind benz(a) pyrene so firmly that the substance is carried deep into the lung and retained there for many days, apparently long enough to cause true squamous cancer of the lung in 70% of exposed experimental animals.

The lung may react in various ways. Airway narrowing and fibrotic and granulomatous reactions have been mentioned. Extreme airway-calibre changes occur in asthmatics. Secretion of mucus is one mechanism for buffering and dissolving gaseous pollutants and trapping particulate pollutants. Chronic bronchitis is a persisting and exaggerated form of this defence mechanism. The effect on the mucous membrane can lead to its secretory layer being thickened or its secretion being thicker or more viscous. The ciliary beat may be directly affected. This has been demonstrated experimentally in animals after exposure to high concentrations of some of the substances in polluted air. If the layer of mucus is thick and the rate of transport slowed, bacteria and other inhaled substances may remain in the lungs after the initial deposition.

Studies are needed on the effect of different air pollutants on the clearing capacity of the lung, and on the effects on ciliary activity and on thickness and viscosity of the mucus. It is also important to study further the absorption in the upper airways of different gases, such as sulfur dioxide and ozone.

Of the substances listed in Table 2, sulfur dioxide, sulfuric acid, some of the sulfates and fluorine are primarily acute, rapidly reacting, irritants of the respiratory tract. To these may be added other pollutants, better known from occupational experience, such as chlorine, formaldehyde and acrolein.

Reactions to ozone, nitrogen dioxide and some metallic oxides may be acute and severe, but the onset is often delayed for some hours.

Reactions to pollens, cotton and flax dust, and castor bean pomace are thought to involve some immunological or other time-dependent mechanism.

Beryllium, asbestos and nitrogen dioxide have specific long-term effects, the manifestation of which may not be fully developed for months or years.

Evidence of long-term effects on man

There have been a number of reports of long-term respiratory tract effects with a suspected relationship to air pollution. For a more adequate statement about effects than can now be made, epidemiological studies of cardiopulmonary conditions and respiratory function must be supplemented with controlled human and laboratory exposures at realistic levels and with realistic combinations. Such studies in each instance must take into account the role of cigarette smoking, of occupational exposures, and of extraneous variables before a "cause–effect" relationship of air pollution and chronic respiratory conditions can be accepted.

Chronic non-specific lung disease. Bronchitis morbidity and mortality in Great Britain have been related (in part) to air pollution by a series of careful studies. As these have been reviewed elsewhere in detail[1] they are not discussed here. In similar studies in other countries, chronic cough and sputum alone have been shown to have a similar prevalence in many areas with different levels of pollution and these symptoms occur more frequently in cigarette smokers than in non-smokers. However, the frequency of shortness of breath and protracted episodes of respiratory disability was greater in London than in rural England or cities in other parts of the world. Respiratory function tests give a similar pattern. Similarly convincing evidence has been presented from Japan that chronic respiratory conditions are more frequent in polluted areas.

In the USA, emphysema is a more frequently reported cause of death in urban than in rural areas. The relationship of emphysema to air pollution is not yet proven as clearly as for chronic bronchitis, but possible differences in the reporting of chronic bronchitis and of emphysema may account in part for this.

Health effects of pollution on children. Studies on children using nutritional and respiratory function tests have shown that anaemia, morbidity, altered development and respiratory conditions are associated with air pollution.

¹ Lawther, P.J., Martin, A.E. & Wilkins, T.E. (1962) *Epidemiology of air pollution*, Geneva, World Health Organization (*Publ. Hlth Pap.*, No. 15).

EVIDENCE OF RESPIRATORY AND OTHER EFFECTS FROM LABORATORY STUDIES

Combined exposures

Table 2 shows very clearly that, at normal current levels of air pollutants, or those of the foreseeable future, the potential threat to health on a long-term basis may be expected to arise not as much from any single air pollutant as from air pollutants in combination, either with other air pollutants or with infectious micro-organisms.

Both animal and epidemiological studies support this statement on the potentiating effects of air pollutants. It has been shown that a single exposure of mice to trace quantities (a few ppm) of the respiratory irritant ozone increased the death-rate of mice either previously or subsequently infected with *Klebsiella pneumoniae*. Nitrogen dioxide at levels as low as 0.5 ppm similarly synergized the effect of this micro-organism but only after nearly continuous exposure for more than three months. True squamous cancers in the lungs of mice, similar to those found in man, were produced by exposing the animals first to infection with an influenza virus and then to large doses of ozonized gasoline. In the animals exposed to ozonized gasoline alone, there were no significant changes; in those with infection alone, approximately 8% showed squamous changes in the bronchi consistent with the healing process after infection, with only an occasional metaplastic change; however, 30% of the animals exposed to the combination showed squamous carcinoma. Thus, the imposition of infection on an air-pollution exposure can reveal the effect of air pollution.

Functional studies

Use of the whole-body plethysmograph has resulted in many valuable observations on the effects of respiratory irritants on gaseous flow, intrapleural pressure and tidal volume in both man and animal. Changes in these parameters have been related to known concentrations of sulfur dioxide, sulfur trioxide, ozone, sulfuric acid vapours, automobile exhausts and others, alone and in combination with solid, particulate aerosols. Similarly, the respirometer may be used to measure changes, both in animals and man, in respiratory function (oxygen consumption) after inhalation of air pollutants and thus provide a sensitive measure of physiological alterations in the lung. The rate of diffusion from alveolus to blood of carbon monoxide (DL_{CO}) can be used in man to measure the interference of pollutant exposure with exchange of respiratory gases and, if combined with other measurements, e.g., of vital

capacity and forced expiratory volume, to locate the site of action of the air pollutant. The effects on ciliary beat and mucous membranes of the upper respiratory tract can be used to estimate the harmful potential of air pollutants, both particulate and gaseous. Changes in thickness of the secretory layer of the mucous membranes or in the viscosity of mucus can also be measured. The effect of air pollutants on lung clearance capacity and the rate of absorption of gases, vapours and particulates in the upper and lower airways offer additional methods of evaluating the effects of air pollutants.

Biochemical studies

Biochemical measures of various kinds provide useful indices of derangements in the normal functioning of organisms. Although they are often nonspecific, they are important sources of information in toxicological studies in the laboratory and could be usefully extended to the evaluation of the effects of exposure of humans to pollutants. The relationship of such changes to long-term effects is not generally known.

The rate of release of ^{131}I by the thyroid provides an estimate of the toxic stress on the homeostatic mechanism. In animals this has been used to study air pollutants of the respiratory irritant type. The method can be used to measure other responses of the thyroid to toxic stress, namely the refractive and hyperactive states. Because of its sensitivity it would be useful to make a comparative study of this method with that of behavioural responses. Similarly, changes in adrenal function in response to substances entering the respiratory tract may be measured by determining urinary corticoids.

Quantitative measurements of changes in enzyme activity, the products of enzyme activity (body metabolites), or enzyme cofactors offer basically sound biochemical approaches to the early detection of metabolic alteration resulting from long-term exposures to air pollutants. Biochemical indicators are numerous, and selection should be made to suit the toxicological needs.

Significant diminution in reduced glutathione (GSH) in the lung has been measured in animals after chronic exposure to air pollutants (oils). These changes appeared before any evidence of histological change. GSH is a requisite for cellular membrane integrity and for the activity of many important enzymes. Thus, those enzymes that depend on thiol (SH) groups for activity are also good indicators of biochemical changes. The change in serum protein ratios, particularly the albumen to globulin (A/G) ratio, determined by paper electrophoresis, is a good general indicator of metabolic derangement. Ultraviolet absorption

spectroscopy is a rapid way to detect and follow changes in the blood and tissues. The more sensitive immunological techniques for detecting circulating or fixed antibody may be used with certain of the more reactive air pollutants. Changes in this defence mechanism of the body can have important implications in the assessment not only of the degree of toxic stress but also in the elucidation of the mechanism of action of the pollutant. Other immunological methods have been suggested: counting of plasma cells and the quantitative determination of change in the capacity of the body under toxic stress to develop antibodies upon immunization. Further study is needed in these areas.

Effects on reproduction and animal genetics

In addition to the "standard operating procedures" of toxicology long used for the detection of chronic changes, such as body weight, food intake, organ-to-body weight ratios, haematological and histological changes, very useful results may be expected from the effects of low-grade exposures on the reproduction of small animal species (mouse or rat) through the F_2 generation.

Storage of pollutant

Trends in storage and accumulation of inorganic and organic pollutants and their metabolites may be determined by spectrochemical or chemical methods in body tissues and fluids. Information already exists on the normal accumulation of metals in man in some countries that can serve as a baseline from which to judge changes in pollutant storage and accumulation. Spectrochemical or, preferably, chemical analysis of the lung and liver for metal shifts of essential trace elements such as copper, molybdenum and zinc reveals remarkable changes in the tissue content of animals on long-term exposure to air pollutants.

Production of tumours

A highly sensitive procedure is the use of a lung-tumour-susceptible strain (e.g., CAF_1/Jax) of mice of known high tumour incidence. Exposure of this, or a similar, strain of mice to air pollutants and the periodical examination of the lungs for tumours, and comparison with suitable controls, may be used to measure the lung-tumour-accelerating (or inhibiting) potential of the air pollution.

CONTROL AND PREVENTION OF AIR POLLUTION

The control of air pollution is ultimately an engineering problem. In principle it should be possible to reduce environmental air pollution below the levels recommended by air-quality guides by applying one or more of the following procedures: (*a*) containment, i.e., prevention of escape of toxic substances into the ambient air, (*b*) replacement of certain technological processes or fuels by new ones that produce less air pollution, or (*c*) reduction of the concentration of toxic substances in air by dilution. These three engineering methods may be supplemented by restricting the use of substances that may become air pollutants.

Containment can be achieved by a variety of engineering methods, such as enclosure, ventilation, and air cleaning, that are highly effective, particularly in nuclear sanitary engineering. It should, however, be pointed out that the improvement of containment methods has been accompanied by a considerable rise in the operating cost and that the economic factor often seriously hampers their application. It should also be noted that containment methods, although very useful, are never completely effective.

The second principle of engineering control, that of replacing a technological process that causes air pollution by a new one that does not, has been considerably less successful in practice. The reason is obvious. The substitute process has to be technologically equivalent to the old one in all essentials, such as the quality of the final product and the availability of raw materials, and it has also to be satisfactory as regards cost of production. All these requirements are difficult to meet and call for costly long-term industrial research, accompanied by similarly expensive and lengthy toxicological research. But substitution may in certain cases be the only solution to a specific air-pollution control problem. The restriction of the use of potentially harmful new synthetic chemicals depends on the availability of adequate substitute substances or processes.

The third principle, dilution, should be used only if the first two methods are not applicable or are unsatisfactory for either technological or economic reasons, but it should be remembered that dilution is valid so long as it is within the self-cleaning capacity of the environment. For example, some air pollutants are readily removed by vegetation. The capacity for this is, however, limited and trouble occurs when the atmosphere is overburdened with pollutants.

4. WATER POLLUTION

HEALTH SIGNIFICANCE OF INCREASING POLLUTION

The total natural freshwater resources of the world and of each general area of the world are relatively fixed by hydrological forces. The use of these resources, however, is increasing rapidly as a result of continued population growth and industrial expansion. Along many of the major rivers in highly developed countries, fresh water is used over and over again as it flows from highlands to the sea. Each use changes the quality of the water, generally to the disadvantage of subsequent users and of aquatic life. There is a limit to the waste product that a stream or lake can assimilate without serious effects on man's physical, mental and social well-being. This limit has been reached or exceeded in many instances.

In almost all of the developed countries, there is growing concern over the ever-increasing introduction into the water of chemicals and radioactive materials with carcinogenic, toxic, and physiological effect on man.

In spite of the increasing complexity of microchemical pollution water-borne infections are still important. Water-borne outbreaks of typhoid fever still occur whenever favourable epidemiological factors coincide with inadequately treated water supplies. High carrier rates and high resistance to chlorination by the enteroviruses are two factors in the prominence of such virus diseases at a time when the enteric bacterial diseases are declining. The carrier rates of enteroviruses in children under 15 years of age average 10% in the USA and can be expected to be much higher in less developed countries. Little is known of the carrier rates of infective hepatitis, but they may be high where environmental sanitation is poor. The relatively high incidence of this disease, the increasing numbers of small water-borne outbreaks, and the occurrence of epidemics associated with shellfish harvested from polluted waters support this belief.

Free-living nematodes, protozoa, and rotifers are the major groups in the zoological phase of aerobic sewage treatment. They are present in large numbers in the effluent. It should be pointed out that the effluent from a thorough biological treatment contains large numbers of bacteria. For example, if sewage is taken to contain about 10^6–10^8 Escherichia coli per 100 ml, treatment by biological filtration will normally reduce this by one or two orders, to 10^5–10^7 or 10^4–10^6 per 100 ml. When an effluent enters a natural watercourse, such as a stream, the latter receives the viruses, bacteria, and zoomicrobes carried in the effluent. In the treatment

plant, the zoomicrobes feed mostly on bacteria growing on organic particulate matter. Nematodes recovered from effluents from trickling filters and primary settling plants have been found to contain in their gut small numbers of *E. coli* and streptococci. Pathogens can survive one to two days inside the nematodes. In times of large epidemics, many persons are discharging pathogens into the sewage and these nematodes may then serve as carriers.

Other zoomicrobes, especially swimming ciliates, feed actively on suspended bacteria, including *Salmonella* and *Shigella* organisms, but they are apparently incapable of ingesting viruses, which are too small to be entrained by the cilia. The ingested bacteria are so rapidly digested that the carrier problem with these protozoa, if it exists, is very remote indeed.

Most biological pollution can be effectively eliminated by most conventional water-purification systems, but in many developing countries the water to which people have access is not necessarily safe. According to statistics compiled by WHO, only 20% of the world's population has access to piped water supplies, and if highly developed countries are excluded, only 5% of the remaining population enjoy this service.

In addition to the chemical and biological degradation of surface waters and ground waters, serious consideration must also be given to physical pollutants, among which heat and radioactivity are the most important.

A high temperature of surface waters is accompanied by deaeration and a resultant loss of dissolved oxygen, with marked effects on the fauna and flora of the water. Not only is the supply of oxygen reduced but its rate of use for metabolic processes is increased; hence heat contributes doubly to the deoxygenation of surface waters. Thermal pollution is also serious in that it interferes with the subsequent uses of water by industries and municipalities.

It is not only the pollution of fresh water that must be considered. For example, migratory fish such as salmon pass from the sea, through estuaries, to freshwater streams. In many industrial countries there are large towns and factories on the banks of estuaries, which in consequence are often much more highly polluted than the freshwater streams emptying into them. This is certainly the case in the United Kingdom, where important salmon fisheries have been destroyed through estuaries becoming impassable to adult and immature salmon, even though the rivers discharging into these estuaries are themselves comparatively unpolluted.

CHEMICAL CONTAMINATION OF WATER

Sources of pollutants

The chemical contaminants that enter the surface and ground waters of the earth do so in three principal vehicles: (1) wastes and waste waters from sewered and unsewered communities, (2) wastes and waste waters from industry not connected to public sewerage systems, and (3) surface run-off and underground seepage from rainfall collected by the drainage systems of urban and rural areas.

Within sewered communities, households and institutions are major contributors of spent synthetic detergents, industries less so. Conversely, industries are the principal contributors of other synthetic organic substances, either as waste products of their own manufacture or as spent liquors from other manufacturing processes. Discharges into water vary in kind and concentration with the nature of the industry and the conditions of manufacture. The concentration and, in the case of non-persistent substances, the nature and concentration of their intermediate and end-products of decomposition are normally altered by sewage treatment before effluents reach watercourses. The type and intensity of cleansing operations are, therefore, important in chemical water management.

In unsewered communities discharging wastes to the soil or possibly to the land and thence to watercourses, underground waters and surface supplies may also be contaminated. Where water is drawn from the ground and the resulting waste water is returned to it through nearby leaching devices, spent chemicals may remain substantially unchanged in constitution and concentration.

Industries requiring large quantities of process or cooling water are often situated on important water-ways. With direct communication between intake and discharge through the works, the opportunity for the release of unaltered chemical wastes by intent or accident is increased.

Run-off and seepage from rainfall in urban areas appear to be of importance in modern cities chiefly when rates and duration of precipitation are high enough to cause appreciable quantities of sewage and scourings from combined systems of sewerage to spill into waters that are otherwise well protected against pollution during dry weather or when rainfall is light. Shock loads of waste chemicals may then be poured into receiving waters and travel downstream in "piston flow" or move about in lakes, ponds and reservoirs as slugs high in concentration of pollutants before their ultimate dilution by dispersal.

Little is known about the chemical pollution of so-called natural

run-off and seepage, but it can be assumed that these intermittent flows contain suspensions and leachings of substances added to cultivated lands, fields or forests or washed from paved areas, particularly factories.

Nature and concentration of pollutants

The degree of pollution with chemicals and the size of the population at risk are obviously the main factors determining the danger being created. The composition of the population and the amenability of chemical pollutants to removal, modification, or destruction by common or specialized treatment processes are significant but lesser determinants.

Synthetic detergents. That synthetic organic chemicals do reach both surface and underground waters and may do so in appreciable concentration has been amply demonstrated by unsightly foams covering rivers, ponds and lakes and issuing from springs and wells. Because the persistent anionic detergents, which are almost wholly responsible for these visible signs of water pollution, are non-toxic in the concentrations normally encountered — although information on the effects of long-term ingestion on man is not yet fully documented — administrative action against their use is based primarily on aesthetic grounds. In water supply, however, palatability and attractiveness, although secondary to non-toxicity, are not factors that can be lightly brushed aside. Of further interest is the inclusion in detergent formulations of so-called "builders", which contain, among other things, condensed phosphates as sequestering agents. These, too, are non-toxic, yet they are key elements in the eutrophication of lakes and other deep bodies of water. By providing essential nutrients to algae, diatoms, and other plankton organisms, phosphates increase the number and intensity of blooms or sudden growths of these organisms in large numbers. Unsightly and odoriferous scums are formed and interfere with the enjoyment of bathing waters. Moreover, they make the production of adequate amounts of palatable drinking-water difficult.

The effect of detergents in reducing oxygen transfer across air–water interfaces is of great economic importance. It has been estimated, for example, that the introduction of synthetic detergents into the River Thames reduced the absorption of oxygen from the air by about 20% and was equivalent to the discharge of crude sewage from a population of about one million people.

Identification of synthetic organic chemicals in water. With some exceptions, the toxic hazards of modern synthetic chemicals that find their way into drinking-water are not known with certainty; nor can

we expect rapid acquisition of the necessary knowledge until we are able to identify the nature and concentration of the pollutants that may be of concern.

By using the carbon–chloroform extraction technique, which involves passing almost 20 000 litres of river water through a carbon filter followed by extracting the adsorbed materials by chloroform, it has been possible to recognize a gradation of river waters in the USA from relatively clean waters to waters seriously polluted by industrial wastes. An example of light domestic pollution is the Columbia River at Bonneville Dam, Oregon, with 24 parts of CCE (carbon–chloroform extract) per 1000 million; one of heavy industrial pollution is the Kanawha River at Winfield, West Virginia, with 457 parts of CCE per 1000 million. Moreover, DDT, aldrin, o-chloronitrobenzene, tetralin, naphthalene, chloroethyl ether, acetophenone, diphenyl ether, pyridine and other nitrogenous bases, phenols, nitriles, acidic materials, miscellaneous hydrocarbons (including substituted benzene compounds), kerosene, synthetic detergents, aldehydes, ketones and alcohols could be identified in the CCE. Some of these substances are known to be toxic. Many other compounds, undoubtedly present, remained unidentified. The application of chromatographic and spectrophotometric methods has since made analysis easier. It has been possible to identify in river water representative chlorinated insecticides in concentrations of less than 10 parts per 1000 million by carbon-filter sampling, adsorption chromatography, and infrared spectrophotometry.

Accumulation of contaminants. Of much significance is the fact that present methods of waste-water treatment leave many dissolved chemicals unchanged. Consequently, the concentration of contaminants increases as water is re-used. Downstream communities are then exposed to increasing concentrations and varieties of chemical pollutants. For example, the heavily polluted Detroit River near Wyandotte, Michigan, and the Merrimack River at Lawrence, Massachusetts, yielded, respectively, 465 and 743 parts of CCE per 1000 million. At Chanute, Kansas, waste water recirculated through a reservoir on the essentially dry Kaw River contained 992 parts of CCE per 1000 million. (These figures may be compared with those for the Columbia and Kanawha Rivers, given above.)

Pesticides in water. DDT has been found in several large rivers of the USA in concentrations of 1 to 20 parts per 1000 million. Pesticides applied to vegetation or soil for the control of agricultural pests may suffer a variety of fates. Part or all of the pesticides may be (*a*) incorporated in part into plants or remain on them as residues; (*b*) volatilized; (*c*) fixed in the soil, to be partly degraded or left unchanged; and (*d*)

leached from the soil by rain or irrigation water to appear as run-off or percolation. Transport and degradation vary with the particular chemical and its contacts. Much has been done to discover the fate of pesticides for the benefit of the user of the product; little for the benefit of water-quality management. The significance of a potential threat of pesticidal chemicals to drinking-water supplies remains to be elucidated by further investigations and research. Nevertheless, it is clear that the widespread use of chemical pesticides has created a new water-pollution problem that cannot be solved in the same way as problems connected with the discharge of sewage and industrial waste have been solved in the past. The economic usefulness of pesticides is so great that increasing quantities of these synthetic chemicals must be expected to reach water supplies. Accordingly, we should be prepared to remove them whenever they appear in significant concentrations. The current trend, however, is to avoid difficulties by developing less stable pesticides for use in agriculture.

Carcinogens. Petroleum products and refinery wastes are generally listed among possibly mutagenic and carcinogenic substances. That there are surface waters into which industrial plants discharge wastes containing substances of this nature has already been suggested. The recovery of various polycyclic aromatic hydrocarbons, including the known carcinogens 3,4-benzpyrene and 1,2-benzanthracene from sewage sludge has been reported. Effluents from gas-works, run-off from macadam roads, and atmospheric soot washed from the air by rain are suspected of introducing these chemicals into sewage. Carcinogenic aromatic amino compounds, such as β-naphthylamine and benzidine, originate in factories making dyes and synthetic rubber and may be released to public sewers together with nitro-analogues used in the production of amino compounds, e.g., aminoazodyes, aminostilbenes, and tri- and di-phenylmethane dyes. Pharmaceutical works, textile dyehouses and plastics-production plants are other sources of these organic substances. Some of the intermediates, e.g., *o*-chloronitrobenzene, have been found in the Mississippi River in appreciable quantities. They may be fairly stable. For example, *o*-chloronitrobenzene discharged to the Mississippi at St Louis, Missouri, was still present in water drawn at New Orleans, Louisiana, hundreds of miles or many days' flow away.

It must be concluded, therefore, that there is reason to suspect the presence of possibly dangerous compounds in polluted waters and that prolonged or life-time consumption of water from polluted sources will increase the normal burden of carcinogens from all sources. In the absence of reliable methods of analysis for dangerous compounds,
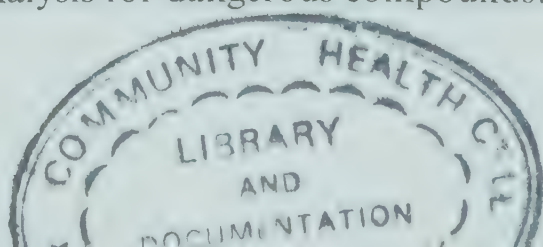
we must turn to longitudinal epidemiological studies of populations at risk to provide the necessary evidence — in this case, unfortunately, only circumstantial. Ultimate decisions on the conditions and degree of exposure of populations must rest on information derived from careful studies of the fate of pertinent chemical pollutants.

Toxicological standards

In reference to the newer synthetic organic chemicals, there is an urgent need for close study of man himself in relation to his ingestion of relatively small amounts of possibly dangerous substances over a prolonged period. Information based upon bioassay through various aquatic organisms, as presently conducted, is not directly applicable to man. Fish, for example, can absorb and release toxicants without necessarily metabolizing them. Accidents, so useful in identifying levels of acute toxicity in industry, would not necessarily tell much about chronic poisoning. Current methods of testing for chronic toxicity on experimental animals are normally conducted on groups of animals that are relatively small when compared with the size of human populations likely to be exposed. Therefore, effects with a low incidence may go undetected. Moreover, studies on animals are not expected fully to reflect the effects of toxic substances on man. Synergism and additive effects of toxicants are possible and should be studied.

In the circumstances it may be possible to adduce information from experience in industrial hygiene, especially when the toxicological data on which industrial standards have been based include animal feeding experiments as well as observations of the reaction of substantial populations at risk.

The feeling of many public health authorities is that no permissible concentration should be set at this time for known carcinogens among the new chemicals.

Aquatic foodstuffs

Fish and shellfish constitute almost the sole human food that comes from natural waters. The vertebrates are sensitive to a wide variety of organic chemicals. Consequently, suitable species are used in bioassays to detect chemical pollution. Since the most probable effect of chemical pollution of water is the death of the fish tested, the danger is easily recognized. However, it is possible that fish and other aquatic creatures used as human food may prove unsusceptible to substances that are very poisonous to man. For example, an "epidemic" of neurological

disease was attributed to the eating of fish that had accumulated alkyl mercury compounds from a factory effluent discharging to fishing grounds in the sea. This potential danger underlines the need for care in keeping dangerous factory effluents away from sources of human food.

CURRENT PROBLEMS

Synthetic detergents and their residues

The history of pollution by detergents may serve as an example of the consequences of introducing a new type of microchemical contaminant into the aquatic environment, and of the measures that have been taken to alleviate the nuisance caused thereby. The household detergent mixtures that began to be marketed on a large scale some fifteen years ago contained as their essential component an alkylbenzene sulfonate (a molecule comprising a benzene nucleus to which was attached a sodium sulfonate group and an alkyl chain containing usually eight or more carbon atoms). The first compounds used contained a branched alkyl chain—a circumstance later found to be of particular importance, although its significance was not realized when the compounds were first marketed.

It soon became apparent that this type of surface-active material is particularly resistant to decomposition by bacterial action. In this respect it is very different from the soaps that it replaced, since these undergo rapid decomposition and do not give rise to any particular difficulty in waters to which they are eventually discharged.

Because of their resistance to bacterial attack, the early alkylbenzene sulfonates were only partially decomposed during treatment of sewage, and approximately half the quantity originally present was subsequently discharged with the sewage effluent. A characteristic property of these substances is that they reduce the rate at which oxygen is transferred from the gas phase to solution in a liquid. Since the purification of sewage by bacterial action is essentially an aerobic process, efficient solution of oxygen is very important, and expensive methods of aeration are necessary to achieve it. Thus detergent residues, by interfering with this process, greatly increased the cost of sewage treatment. If additional aeration plant was not provided, there was a serious deterioration in the quality of the treated effluent.

Moreover, the residues discharged to surface waters also caused a serious deterioration in their quality. The unsightly foaming that occurred in many rivers, particularly below turbulent reaches, is well

known. Another less obvious, but equally important, effect was that the rate of solution of oxygen from the air by the surface water was reduced, so slowing the processes of self-purification below points of discharge of sewage effluents. Furthermore, it has been held by some workers that detergent residues have an adverse effect on aquatic plants and animals. This perhaps applies where the residues are present in unusually high concentrations.

After much technical discussion on possible methods of dealing with these difficulties, it has now been widely concluded that the most (if not indeed the only) practicable step is to develop substitutes for the original form of surface-active material that are more susceptible to bacterial attack. This has led to a great amount of research by manufacturers. Many hundreds of experimental materials have been tested, and the goal of producing substantially or wholly degradable substances on a large scale may now be said to be in sight.[1] One clue to the direction to be taken was that it was found that if the alkyl side-chain was straight instead of branched, resistance to bacterial decomposition was greatly reduced. This brief history is presented as a background to the more recent problem posed by the increasing use of other synthetic organic substances, notably pesticides.

Other synthetic organic substances

The presence of persistent synthetic organic substances in sewage could constitute a health hazard only where the effluents reach sources from which water is later taken for domestic or municipal supplies. It is, of course, assumed that the water from such polluted sources would be adequately treated and disinfected before distribution. Where this has been done, the evidence available is that the treated water has no adverse effect on human health. For example, in the United Kingdom, where part of London's supply is taken from rivers that have received sewage effluents, and part from deep wells, the returns of health statistics submitted by the Registrar General have not so far revealed significant differences between health indices of the communities served by the two sources. Presumably if the concentration of these organic biologically resistant substances is increasing in waters used for public supply, it is to the extent that the concentration of sewage effluent in the waters is itself increasing.

There has, however, been a more rapid increase (at least in industrialized countries) in the quantities of persistent organic materials

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[1] A high proportion of the synthetic detergents in use in 1966 was largely degradable. Whether these substances are more or less toxic than the older synthetic detergents is not yet known. One study suggests that they — or their degradation products — are more toxic to fish than the older synthetic detergents.

discharged into water systems from industrial processes of all kinds, e.g., from the oil and chemical industries. Some of these substances have been identified and determined by refined modern techniques. The presence of at least some of these contaminants in water used as a source of domestic supply is certainly undesirable. In many cases, however, a technical remedy is available, i.e., the application of existing treatment methods or the development of new ones to remove the compounds from industrial effluents before their discharge.

Much of the research on the environmental side-effects of synthetic organic pesticides has been undertaken in the USA. Elsewhere — in the United Kingdom, for example — the level of application of pesticides and the resulting mortalities among wildlife are clearly much lower. Nevertheless, the United Kingdom too can point to recent noticeable bird losses. Much wildlife loss attributable to pesticides does not concern aquatic habitats. However, with specific respect to the latter, the American data still furnish reliable evidence that various organisms have suffered harm on a significant scale. It is mainly on this evidence that we must at present depend in predicting what the consequences may be in other countries where increasing amounts of synthetic organic pesticides are being used.

In the first place, pesticide residues in concentrations of 0.1 to 5 parts per thousand million have been found in the major river systems of the USA. In some rivers in the United Kingdom, fully chlorinated hydrocarbon pesticides have recently been found in concentrations exceeding 1 part in 10^9. Such concentrations are small, but their effects are far-reaching. Thus the direct toxicity of some pesticides to fish is extremely high, as is shown by the fact that within four days half of a test sample of trout had died as a result of exposure to endrin at a concentration of only 0.5 parts in 10^9.

Secondly, it is well established that pesticides present in small amounts in water can be concentrated many-fold by aquatic organisms, including algae, and that the degree of concentration may thereby increase from link to link in the food chain. Thus, although fish may not themselves be killed at lower levels of such microchemical pollution, their bodies may nevertheless contain sufficient pesticide residues for the ingestion of numbers of them to harm or cause the death of birds that feed on them. In this connexion, it is relevant that in the United Kingdom the first indication that a serious state of affairs might be developing was the finding of high concentrations of residues in fish-eating birds; despite regular observation and investigation, no deaths of fish in surface waters have so far been attributable to pesticides, except on a very few occasions through abnormal causes, such as accidental discharges.

In the USA there is much circumstantial evidence for the claim that in some districts fisheries are being seriously threatened by pesticide hazards. For example, in New York State the reproduction of trout is known to have been reduced significantly at the time when the egg-yolk (in which DDT had accumulated) was being absorbed by the developing fry. In other areas, there has been a massive mortality of fish immediately after pesticides have been applied by spraying from aircraft. Sometimes deaths have occured after the first rain following spraying, and experiments in Georgia demonstrated the toxicity to fish of run-off water from a sprayed area.

Long-continued assessments of the results of aerial forest spraying for the control of spruce budworm in the drainage basins of many leading salmon rivers in New Brunswick, Canada, have furnished much specific information on the consequences to aquatic organisms. In most operational sprayings between 1954 and 1960, DDT was applied at 0.5 1b/acre (0.6 kg/ha). After such treatments, the aquatic insect fauna typically declined sharply, emergence being nullified for up to six weeks. It was found that the larger bottom-dwelling species, which are the preferred food of larger parr,[1] required long periods to become re-established: stone-flies needed at least two years, mayflies three years, and caddis-flies four years. Not until after 4-5 years with no further spraying did the species composition of aquatic insects return to normal. As regards direct harm to fish, young salmon of all size-groups were found in greatly reduced numbers after spraying. For under-yearlings the numbers were only 2%–10% of those before spraying, while for small parr the figures were 30% and for large parr 50% of those in unsprayed locations. The rates of growth of the survivors were also affected adversely because of the disturbance of their food supply, as already mentioned. Since 1960 DDT has been applied to a considerable extent, at 0.25 1b/acre (0.3 kg/ha). Single applications at this dosage have resulted in appreciably lower fish mortalities. and recent trials with the systemic insecticide phosphamidon, at 0.5 1b/acre (0.6 kg/ha), have indicated that it is a promising substitute for DDT, causing in-significant harm to fish populations and giving no demonstrable effects on aquatic insects in three weeks following spraying.

Again, the employment of extremely sensitive methods of chemical analysis to investigate recent massive fish mortalities in the lower Missis-sippi river has demonstrated that the concentration of endrin in the blood of these fish was sufficiently high to have caused their death. More surprisingly, it is now being reported that marine fish (even in comparatively open ocean waters) contain measurable concentrations

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[1] Most New Brunswick young salmon spend three years in rivers migrating to the sea; they can be placed in three size-groups roughly comparable to each year of life, namely under-yearlings, small parr and large parr.

of pesticide residues. In fact, some of the most striking evidence for the accumulation of residues of pesticides has come from the examination of estuarine and marine fish and the sea-birds feeding upon them. An early and very well-known example of the extent to which such residues can accumulate in fish-eating birds was provided by Clear Lake, California, USA. In 1954 and again in 1957 this lake was treated with DDT at a concentration of 0.02 ppm for the control of the non-biting gnat *Chaoborus astictopus*; after the second application, breakdown products of the compound were detected at a level of 1600 ppm in the fatty tissues of western grebes found dead there. Very recently, figures have been obtained for the concentrations of DDE and dieldrin in the eggs of British fish-eating birds feeding from waters to which synthetic organic compounds had never been directly applied for pest control. As examples of the levels found, from 8 ppm to 28 ppm of DDE and dieldrin together were found in the eggs of herons (*Ardea cinerea*) and from 1.6 ppm to 3.2 ppm in those of terns (*Sterna* spp.).

LONG-TERM DANGERS OF WATER POLLUTION

The establishment of drinking-water standards differs in one notable way from the establishment of air standards for occupational exposure; the number of substances in water whose limits are regulated is kept to a minimum because the promulgation of a standard is tantamount to the requirement of periodic analytical checks to assure compliance with the standard, which is impracticable when hundreds of substances are included. Two regulatory devices are, however, used in water pollution which make it unnecessary to test for a large number of individual substances:

1. Use of limiting concentrations of indicator substances, e.g., alkylbenzene sulfonates, as an index of synthetic detergent pollutants, water re-use and general level of contamination.

2. Use of group analysis, e.g., of total dissolved solids (TDS) and of substances that can be extracted by chloroform from carbon filters (CCE) as indices, respectively, of inorganic and organic chemical pollution. Thus, a single analysis may provide an index of either total dissolved mineral or total organic pollution present.

In warm climates, a much greater daily drinking-water intake can be expected than in temperate countries, and up to fivefold greater amounts of water may be consumed. The populations of the former, therefore, might ingest up to five times as much water-borne pollutants as the latter, with equal concentrations of pollutants in drinking-water. Much of the work on existing standards is based on intake in temperate

climates, and criteria for their application to warmer areas should be developed and applied. Important mechanisms that produce synergism *via* the respiratory tract are not operative in the gastro-intestinal tract; an example is the adsorption of gases and vapours on particulates. The apparently potentiating effect of micro-organisms and pollutant combinations in the lung does not appear to be of importance in the gastro-intestinal tract. As in the lung, however, the potentiated action of carcinogens by promoters and accelerators still obtains.

There is undoubtedly concern among laymen, as well as among scientists, that man is ingesting pollutants of food and water that may have now, or in the future, adverse effects on human health. They point out that industry is producing many new substances that find their way, either intentionally or unintentionally, into food and water. They fear that these substances have been introduced without sufficient evaluation of their possible health hazards.

Food may be, quantitatively, a more important source of ingested pollutants than water. The following discussion will be focused on pollutants of water, but in any consideration of the effects of ingested pollutants on health the contribution of food cannot be excluded.

Water as it occurs in nature is always a dilute aqueous solution of organic and inorganic substances. Potable water is generally considered to be a colourless, clear solution without unpleasant odour and taste, which contains no more than 1500 mg/litre of total solids and no more than specified amounts of certain contaminants.[1] In addition to meeting standards of chemical purity, potable water must also conform to certain standards of microbiological purity.

Not every possible pollutant of water, however, is identified in the International Standards and there are many pollutants for which safe limits have not been specified. Hence water conforming to the International Standards may, in fact, be unsafe and may produce adverse long-term effects on health. There is no scientific evidence, however, that such adverse effects on health have been produced as yet. There remains only the fear that they might occur in the future.

The number of inorganic water pollutants is smaller than the number of organic pollutants. The most important inorganic pollutants have been identified in the WHO *International Standards for Drinking-Water* and safe limits for them have been recommended.

Metals in water

Mineral pollutants other than those listed in *International Standards for Drinking-Water* may occur from time to time in specific places.

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[1] WHO (1963) *International standards for drinking-water*, 2nd ed., Geneva.

In connexion with industrial exposures, there are about 50 metals that are of special interest. Lead and mercury continue to be the most important, but many other metals, e.g., arsenic, beryllium, cadmium, manganese, chromium, nickel and vanadium have become of increasing toxicological importance. Table 3 gives a list of some selected water pollutants having potential long-term effects.

TABLE 3. SELECTED WATER POLLUTANTS, HAVING POTENTIAL LONG TERM EFFECTS

Elements or substances	Indicator substances
Arsenic (As, particularly As_2O_3)	Alkylbenzene sulfonates, ABS (index of pollution by all synthetic detergents)
Barium (Ba)	
Cadmium (Cd)	Carbon chloroform extract, CCE (includes most organic compounds, including organic carcinogens and pesticides)
Chlorine (Cl_2) (with reaction products from organic pollutants may have toxic potential)	
Chromium (CrO_3)	Phenol (includes phenols, cresols and homologues)
Fluoride (F)	Total dissolved solids, TDS (includes minerals contributing to "hardness")
Lead (Pb)	
Mercury (Hg)	Gross β-radiation (index of mixed radioisotopes in the absence of ^{90}Sr and α-emitters)
Nitrate (NO_3)	
Selenium (SeO_2, SeO_3)	
Vanadium (V)	

The general population is less concerned about industrial exposure than about the exposure to contaminated food and polluted water and urban air. This exposure is not generally large enough to cause clearly demonstrable toxic conditions. It does, however, result in deposits of a number of substances in the body. It is possible to demonstrate the presence not only of substances vital to the body, such as copper, cobalt, molybdenum, manganese and zinc, but also of potentially toxic substances, such as cadmium, chromium, vanadium, nickel and lead. Moreover, certain substances are organ specific whereas others are more evenly distributed in the body. Certain substances show a marked variation in retention in relation to age. The amount of chromium decreases with increasing age, whereas that of aluminium in the lungs and cadmium in the liver and kidneys increases with age.

Specific water pollution by mercury has occurred in the coastal waters of Japan as a result of the disposal of industrial waste. This pollution indirectly caused human disease and deaths through the consumption of fish taken from the waters. The fish had absorbed sufficient mercury from the water to become toxic food-stuffs. Whether the water itself would have been toxic is not known, since it was not used for drinking. This emphasizes the fact that pollutants of water may reach man through food originating in the polluted water.

In recent years, it has been suggested that certain metals in concentrations normally present in the body might contribute to the development of chronic diseases. The hypothesis is that certain essential metals form complexes, e.g., iron and cobalt in the porphyrin chelates, heme and vitamin B_{12}. It is possible that other metals might compete for a ligand with an essential metal on a metallo-enzyme. The administration of one metal might thus create an effective deficiency of another. Cadmium and mercury, stored, for example, in kidneys and testes, might thus displace zinc owing to their chelation with ligands that normally chelate with zinc. This is only an example, but other mechanisms may, of course, be considered. The possible toxicity of trace metals has been raised in connexion with the endemic nephropathy in Bulgaria, Yugoslavia and Romania.

Epidemiological studies carried out in Japan, the USA, England and Sweden have established higher mortality rates from cerebrovascular and cardiovascular diseases in people provided with soft water than in those provided with hard water. The amount of calcium in drinking-water is only a small proportion of what is ingested in food. Calcium in water may, perhaps, be correlated with other substances, e.g., trace elements or organic components. Further epidemiological and laboratory studies might lead to a better understanding of these differences.

Pesticides in water

The pesticides form another class of water pollutant of great interest. Pesticides are a new hazard, not only to the people who are occupationally exposed, but also possibly to the general population. Pesticides can occur in water, soil, and food (including milk, fruits, and fish living in polluted waters), and especially in rural areas, where they are widely used for agricultural purposes, they may also occur in the air.

The pesticides in greatest use today are organic compounds of some complexity, although pesticides based on arsenic, lead and mercury are still used. Pesticides reach water supplies directly as the result of intentional application for the control of pests in the water, or un-

intentionally from run-off from agricultural areas, from careless spraying from aircraft of adjacent fields, from industrial waste disposal and by ground-water and subterranean-water transfer.

Much is known about the toxic effects of ingested organic pesticides. The acute and subacute toxic effects are known for a number of animals and, in many instances, for man. If the pesticide is to be used on raw agricultural products, the chronic toxic effects will have been evaluated in rats and perhaps in dogs on the basis of the addition of the pesticide to the diet for periods of up to two years, or on the demonstration that the pesticide is metabolized to one or more other products whose chronic toxicity is known. This information, which would usually include a level of dietary intake that produces no detectable adverse health effects over the feeding period, is usually a preliminary to the establishment of a maximum permissible residue on raw agricultural products.

Although there is some experience with acute toxic effects of pesticides on man, relatively few examples of chronic toxic effects on man have been recorded. The toxicity of the more important pesticides has been reviewed in a number of FAO and WHO publications.[1]

The ill-effects, if any, of ingesting in water very small amounts of pesticides have yet to be demonstrated. In the absence of direct human experience, reliance must be placed on experiments on laboratory animals. The nature of these experiments will vary according to the practice of different nations, but the basic principles of such work have been set out.[2] In general, such investigations include feeding the pesticide to rats, and in some countries to dogs also, as a part of their diet for two years. Several dietary levels of the pesticide are fed and the lowest dose level should be so selected that the animals receiving it throughout the two-year period will be expected to show no discernible ill-effects. Two years cover most of the life-span of the rat.

The results of the many experiments on animals lead to the following conclusions:

(1) The chronic toxic effects of the pesticide diminish with decreasing dose.

(2) A low, but still finite, dose level can be found that in the lifetime of the rat, and for two years of the life of the dog, produces no detectable toxic effects as measured by growth, behaviour, life-span, reproduction, biochemical and haematological values, and by gross and microscopic pathological examination.

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[1] *Evaluation of some pesticide residues in food* (document FAO/PL: CP/15, WHO/Food Add./67, 32); *Wld Hlth Org. techn. Rep. Ser.*, 1967, No. 370 (*FAO Agricultural Studies* No. 73). The latter report contains references to several earlier publications.

[2] *Procedures for investigating intentional and unintentional food additives: report of a WHO Scientific Group*, Geneva (*Wld Hlth Org. techn. Rep. Ser.*, 1967, No. 348).

Such low levels are called "no-effect" levels and in the USA a residue tolerance for a pesticide on specified raw agricultural products must be derived from a demonstrated no-effect level by the application of a factor of safety, usually of the order of 100, designed to take account of the fact that man may be more sensitive to the pesticide than the laboratory animals used.

It may be objected that conclusions based on experiments on animals are not relevant to man. The effects of drugs on man, however, do follow the general rules deduced from animal experiments in that effects diminish with decreasing dose and disappear at some small but definite dose. Moreover, the method used by the United States Food and Drug Administration to establish safe residue levels of pesticides in food has been based on animal experiments and there is no sound evidence as yet that the method has led to any serious faulty conclusions.

Knowledge of the chronic effects of pesticides in man would be much greater if there were some way of studying them directly in man. Direct experiments of the type required to obtain the most relevant information, however, are excluded on many grounds.

The risk of exposure to pesticides is widespread; for example, in those engaged in the manufacture of pesticides as well as those who formulate and use them regularly. People who live or work in or near areas where pesticides are regularly used may be inadvertently exposed. Thus, symptoms of sensitization and gastro-intestinal, respiratory, nervous and ophthalmic manifestations have been observed in people living in contaminated areas.

5. SOIL POLLUTION

MAGNITUDE AND HEALTH SIGNIFICANCE

Solid wastes are generated from domestic, industrial and agricultural sources. For domestic waste, the quantity of trash and garbage per person varies considerably from country to country, depending on the stage of economic and social development. In metropolitan Los Angeles, for example, the total amount of solid domestic wastes in 1962 equalled about 1400 g per head per day as collected, or about 760 g per head per day on a dry-weight basis. In contrast, the total increment of solids between the water supply and the waste-water

collection system amounted to less than 200 g per head per day (dry weight). Hence, this metropolitan area rids itself of over three times as much dry weight by the solid route as by the liquid one. The annual operating cost for the collection and disposal of solid waste is about three times that for the handling of liquid wastes.

Solid wastes of domestic origin may be incinerated, composted, dumped on the land, buried or disposed of at sea. Each form of handling produces problems of public health. Burning and composting account for the organic wastes only and the ash or inorganic portion must still be disposed of. Incineration, even in the most efficient incinerators, causes air pollution, especially by oxides of nitrogen. Composting and open dumping may increase the population of flies, rats and other vectors of disease. Buried organic wastes are subject to anaerobic decomposition and the production of methane and carbon dioxide may result in pollution of ground waters. Disposal of wastes in sea dumps may cause subsequent jetsam and beach pollution.

Industrial solid wastes have major economic implications but they are generally not a direct hazard to health. Exceptions can, of course, be cited. Major problems arise when solid industrial wastes are burned or ignite spontaneously, thereby adding to air pollution, or are allowed to be leached by rainfall, with consequent pollution of surface or ground waters. The opencast mining of coal, the formation of mountains of slag, and the tailings from mines all represent examples of solid industrial wastes defacing the land and rendering it unfit for many subsequent uses. Important problems develop from the need to dispose of radio-active wastes from reactors and nuclear research centres by burying solid wastes on land or at sea.

Solid agricultural wastes should not contribute to environmental pollution, for plant material is normally returned to the soil. The concentration of these wastes at transfer stations, canning or packaging plants and produce yards, however, has created a problem. Here, huge accumulations of organic debris may decompose, leach from rainfall, attract disease vectors, and so on, with resultant pollution of the environment.

CHEMICAL CONTAMINATION OF THE SOIL

Chemical pollution of the soil results from the unintended or incidental contamination of the soil with man-made chemicals. The pollutants can reach man through the ground water, the run-off or drainage water, and the plants used as food or forage for domestic animals — and, to a smaller degree, wild-life — serving as food. There-

fore, the pollutants must be water-soluble and enter the soil moisture or the water percolating through the soil. Plants may draw their moisture from either source. Seeds diessed with pesticides may, however, be picked up by birds and harm them, and insoluble residues on vegetation may be ingested by cattle.

The soil contains many inorganic and organic substances soluble in water. They are the products of the weathering and decay of minerals and the degradation of organic matter. By microbial action these substances are normally oxidized, in the main to inorganic oxides, but some organic compounds reaching oxygen-free ground-water may not be fully oxidized. Humus substances are found even in the best waters, together with small amounts of so-called trace elements. In nature, the soil gets some of its components from the air — e.g., iodide from small droplet-nuclei generated by the seas — and from wastes from the burning of fossil fuels.

Fertilizers are intended to fortify the soil for the raising of crops, but incidentally may contaminate the soil with their impurities. Irrigation of farmlands and orchards may do this if the source of water is polluted by industrial wastes that contain synthetic organic chemicals.

During the last few decades, herbicides, insecticides, fungicides, soil conditioners and fumigants have produced intentional alterations of agricultural, horticultural and silvicultural soils. The chemicals used may accidentally pollute the soil water.

The soil must be regarded as a living community of fungi, bacteria, protozoa and metazoa. Fumigants and soil conditioners are unstable and are metabolized by the micro-organisms of the soil. For example, even the chlorinated phenol derivatives, such as polychlorophenoxyacyl acids, used as herbicides are metabolized by special strains of bacteria that adapt themselves to use them as nutrients. This holds true also for DNOC (dinitro-o-cresol) and allied compounds. It must be added that the bacterial and fungal flora of the soil are much richer in numbers than the flora of watercourses, even when these are contaminated by organic matter. It is therefore possible for chemicals that can remain unchanged for a long time in water to be rapidly degraded by microbial activity in the soil. For example, by "feeding" a soil with chemicals such as phenols, bacteria that thrive on naturally occurring phenols will multiply.

Experience with new antibacterial drugs shows how effective some bacteria are in developing resistance to new substances. The metabolic enzymes undergo the necessary alteration so as to detoxify the compounds; we speak then of adaptive enzyme formation. By such mechanisms chemicals disappear from the soil, and farmlands must be sprayed every year with herbicides if weeds are to be kept in check.

Ideally, only such chemicals should be employed that have been proved to be readily attacked and degraded by the common soil micro-organisms. Compounds of lead and mercury — the mercurials being mostly organic compounds — and salts of arsenious acids are likely to accumulate as persistent soil contaminants and to introduce lead, mercury and arsenic into plant products.

The present trend in the manufacture of pesticides for use in agriculture is to synthesize short-lived degradable compounds because this minimizes the persistence of residues of pesticides and their degradation products on food and forage crops.

Among the organic pesticides now in use that resist bacterial degradation and have no inert end-products, by far the most important are the chlorinated hydrocarbons, e.g., DDT, lindane, aldrin and dieldrin. Remnants of these stable pesticides appear to be bound to or adsorbed on soil particles, which are made up of inorganic minerals coated with organic compounds. These chemicals may contaminate root crops grown in soils of this kind; for example, lindane can taint carrots or beets. The behaviour of chemicals that do not affect the quality or reduce the yield of crops can escape notice, but true absorption and incorporation of these pollutants by plants is unlikely to occur in normal practice.

On the other hand, water seeping from soil contaminated by chlorinated hydrocarbons has been shown to contain small amounts of these substances. They are probably taken up by the lipid-containing humus of the soil and become part of the soil water. Possible, but yet not proved, is the absorption by man of such substances from drinking-water gathered from such soils. The presence of the substances has been shown by their extraction from the water by strong organic solvents. The amounts recovered are of the order of a few micrograms per litre and it is unlikely that they represent a toxic hazard to man in these amounts.

Observation of the contamination of farmland in the neighbourhood of chemical factories has indicated that there is a potential danger of fall-out from the plume emitted by the smoke stacks of chemical works. However, this pertains only to inorganic contaminants. Synthetic organic chemicals are destroyed in properly operated stacks.

Whereas gaseous wastes enter the atmosphere and liquid wastes are generally discharged to surface waters, solid wastes are usually placed on or in the soil. Some solid wastes are dumped into surface waters, with resultant water pollution, and some are burned, with conversion of much of the solids to gaseous wastes; on the other hand, some liquid wastes are spread on the soil and some are injected into sub-surface strata. The land environment, therefore, will receive most solid wastes and some liquid pollutants.

6. RESEARCH PROJECTS

GENERAL

Research into environmental pollution should embrace both pure and applied research. Research is especially needed on the application of well-known principles to specific situations, particularly in the developing countries.

With regard to the newer organic synthetic chemicals, there is an urgent need for close study of man himself in relation to his ingestion or inhalation of relatively small amounts of possibly dangerous substances over a prolonged period.

Epidemiological studies on groups of people with occupational exposures, or of people living in areas of high exposure, should be undertaken to determine both subjective and objective signs of chronic toxic effects. Such studies should include the measurement of toxicant and metabolite levels in available tissues — hospital specimens and autopsy material. These levels should be correlated with changes in enzyme activity, with changes in ophthalmic, auditory, neural, muscular and respiratory functions, and particularly with tissue levels associated with effects — or the absence of effects — in laboratory animals.

Although the accumulation of pesticides in the tissues of man appears, from present knowledge, to stop when fairly low levels of storage are reached, epidemiological investigations could be undertaken on the diseases caused by abnormal metabolism of carbohydrates or of lipids, on haemorrhagic coagulative diathesis, and on disorders of protein or mineral metabolism, in groups of people with high-level exposure to pesticides. Appropriate control groups would be essential.

RESEARCH INTO MUTAGENICITY AND CARCINOGENICITY IN RELATION TO AIR, WATER AND FOOD POLLUTION

Mutagenicity

Mutagenicity can have long-term effects of significance to health in at least three ways:

(1) Mutation of somatic cells may result in the emergence of new (non-malignant) cell types differing from the normal. If such cells are functionally less effective or interfere with the integrity of the organ, such mutations represent one form of pathogenesis.

(2) Mutation of somatic cells is viewed by many as the mechanism whereby normal cells become malignant.

(3) When non-lethal mutations are produced in the reproductive cells of the parent organism, genetic effects may occur in succeeding generations. The outcome is particularly important where large populations are affected by widely distributed environmental pollutants. Each chemical mutagen could contribute its quota of mutations to those arising from other sources. Accordingly, the genetic consequences of all mutational factors must be evaluated jointly.

Many chemical agents are capable of producing mutagenic effects in one or another biological system. This, however, does not imply that such substances under conditions of actual exposure produce significantly frequent mutations.

Particularly active as mutagens are some of the alkylating agents, some of the so-called "anti-metabolites", and other chemicals structurally related to the bases of nucleic acid. Perhaps many compounds capable of modifying nucleic acid but still permitting replication may lead to mutation. A list of mutagenic chemicals, including those that may occur in the human environment, is included in the third report of the WHO Expert Committee on Radiation.[1] The problem is more fully discussed there.

Tests of chemical agents for mutagenicity can readily be carried out on simple systems, such as phage and bacteria. However, since entry, transport and metabolism are probably important factors in determining the effective dosage of the mutagen, such minimal tests must be reinforced by a study of these biochemical factors in higher organisms before an estimate of the likelihood of hazard can be ventured. Furthermore, some materials not in themselves mutagenic may be converted into mutagens by metabolism. For these reasons, the assessment of possibly mutagenic pollutants should be extended to mammals.

Population studies will no doubt be needed. They will, however, be extremely difficult, because of the problem of quantifying the effects in succeeding generations, and particularly because of the extreme difficulty in defining the actual exposure of the parents to the multiplicity of mutagenic factors.

Carcinogenicity

The extensive and well-documented history of occupational exposure, ranging from the work of the chimney-sweep to the manufacture of chromium compounds, has established the reality and seriousness of

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[1] *Wld Hlth Org. techn. Rep. Ser.*, 1962, **248**, 29.

the consequences of exposure to chemical carcinogens. Nearly every organ of the body is capable of yielding a tumour in response to an appropriate chemical agent. Although the responding tissue is sometimes that directly exposed, e.g., the lung with chromium compounds or the skin with coal tar, on other occasions the tumour develops in a remote organ. An example of the latter is the occurrence of bladder cancer after exposure to certain aromatic amines, for which the chief portals of entry are the skin and the lungs. The effects of various routes of entry of chemical carcinogens are often additive; consequently the entire exposure pattern — water, air, food — needs consideration. An additional complication is that carcinogenesis from chemical agents is usually a consequence of the interaction of a number of factors. This is particularly well illustrated in the classical example of the two-stage mechanism of skin-cancer induction. In this, a dose of polynuclear hydrocarbon, in itself incapable of producing cancer, leads to a high frequency of skin cancer if followed by the application of the promoting agent, croton oil, itself also without carcinogenic effect. Other modifying factors include prior disease (scar cancer of the lung) or infection (influenza virus and ozonized gasoline). In some instances, simultaneous exposure to other toxic agents can impair the capacity for eliminating a carcinogenic agent. An example is injury to the clearance mechanism of the respiratory tract by tobacco smoke. In short, the assessment of effective carcinogenic exposures requires consideration not only of multiple sources, but also of the role of promoting factors.

The most decisive information on the hazards of chemically induced cancer in man has come from epidemiological studies on occupational groups. Studies on groups exposed to general community pollutants have not led to such conclusive results. Thus the role in the production of lung cancer of air pollution by polynuclear hydrocarbons such as benz(a)pyrene is still uncertain. Although there is some evidence of a modest contribution to lung cancer from such sources, the issue cannot be resolved at present. A number of other air pollutants have attracted attention in this regard, among them non-aromatic organic compounds. The role of benz(a)pyrene as an environmental pollutant has attracted much attention; it has been found not only as an air pollutant but also in smoked foods and in soils, and is known to reach water supplies from several sources. Although its quantitative occurrence in such sources is of interest, such findings cannot be interpreted in the absence of information as to the relevance of the observed concentrations for man. The solution of such problems will require both epidemiological and laboratory studies.

Epidemiological studies have provided information on significant differences in the rates of occurrence of tumours of various organs

in different population groups. Such leads can guide the search for etiological factors if this initial information is reinforced by the development of adequate histories of exposure.

Laboratory procedures provide a useful adjunct to epidemiological studies in identifying causative factors. Such procedures, however, are particularly important as a means for predicting the likelihood of cancer from new materials before they are used. There was a dramatic success in such predictive testing in the discovery that the compound acetylaminofluorene, which had been proposed as an insecticide, was a potent carcinogen. Despite such successes, however, the procedures now available are far from satisfactory, either in reliability or in convenience. Most of the accepted procedures for predictive testing involve the examination of moderately large groups of several species of animal over their life-span or a large fraction of it.

Several factors limit the usefulness of such predictive tests. First, species differences have been shown to be decisive in many instances in determining tumour response. Species differences in metabolism of the carcinogen lead to differences in response, and the mere use of more species may not be sufficient. Tests on laboratory animals thus invariably need reinforcement by parallel metabolic studies on man.

Second, the largest groups that can be used in most practical laboratory studies will be much smaller than the population groups exposed. Consequently, extrapolation from high to low incidence levels must be undertaken. On the one hand, the establishment of safe levels is difficult in the absence of general principles for such extrapolation. On the other, the approach based on the assumption of no threshold is possibly too conservative. Therefore, to assist in the establishment of safe levels, a few large-scale experiments (involving large groups of animals) must be carried out to help in defining general principles for such extrapolation.

Third, in many instances secondary factors as noted above (disease, injury and so forth) may be decisive in determining the hazard. Although it will obviously be impossible to examine routinely the large number of such possible variables, these considerations must be kept in mind in planning experimental work. Two suggestions emerge. The testing of realistic mixtures of substances in addition to the pure substances must be encouraged. Also, wherever possible, possible leads to relevant joint promoting factors should be taken into account in the planning of such studies.

A considerable number of short-term tests have been proposed for examining suspect materials for their carcinogenicity. These include sebaceous gland suppression, nucleolar enlargement, various responses

in simple systems, e.g., tissue culture, slime moulds and paramoecia, and biochemical tests such as interaction with nucleic acid. Such tests have proved useful in the examination of the comparative activity of compounds of a similar chemical type. All have, however, failed when applied to the comparison of a wide variety of chemical structures.

In addition, these tests neglect the mechanisms of biochemical handling, which may critically determine effective dose. These include efficiency of entry, storage and metabolism. Metabolic studies on man are a minimal requirement to reinforce the interpretation of the results of such accelerated tests.

AIR POLLUTION

Methods of research in air pollution

(1) *Experimental studies.* The development of quick, simple methods for obtaining valid indices of pollution for use in epidemiological or other surveys is given priority by many workers. Of these methods some lack specificity and their use can lead to erroneous conclusions. Methods for assessing particulate pollution by reference to the optical density of the stain produced on filter-paper require frequent recalibration in gravimetric terms. Instruments to record the concentration of pollutants at frequent intervals are desirable in order that the effects of sharp peaks in pollution can be evaluated. Because some plants and lower animals are more sensitive than man to low concentrations of certain air pollutants, they may be used as "biological indicators", i.e., as cheap and accurate complements or alternatives to complex measuring instruments. The danger of an uncritical application to man of the results from biological indicators must be recognized.

The investigation of exposure of human volunteers to realistic concentrations of urban pollutants separately and in mixtures is obviously preferable to experiments in which animals are subject to massive exposures. Although the investigation of the effects of realistic exposure on various aspects of lung function is of obvious value, experiments on other possible effects should be encouraged; for example, it may be useful to investigate the effects on bacterial flora of the many particulate and gaseous contaminants found in urban air.

(2) *Field studies.* Adequate field studies can yield the most convincing indication of the association between mortality or morbidity and air pollution. Satisfactory studies, however, are dependent on accurate indices of health and of domestic and industrial pollution. They can therefore be carried out only in communities with facilities to compile such indices.

(a) *Pollution indices.* Whereas measurements of many different pollutants may be required for specific research projects, certain parameters should be chosen either by national or, preferably, international agreement for routine use. Furthermore, standardized techniques of measurement should be adopted. With standardized parameters and procedures, it should be possible to establish recommended sampling procedures for different types of areas, such as commercial centres of towns, areas of light or heavy industry, residential areas of different housing densities, and areas in which there is rigid enforcement of smoke-control regulations. In the establishment of these procedures regard must also be paid to the topography and natural ventilation of the areas. The results will, it is expected, facilitate comparisons between different types of areas.

(b) *Indices of mortality and morbidity.* Suitable indices of mortality and morbidity must be carefully chosen. Certain segments of the community, e.g., those engaged in very healthy occupations, may be particularly resistant to the effects of air pollution. Indices such as those based on total numbers of deaths in the population, or on admissions to hospitals, or on applications for sickness benefit are satisfactory in large communities. In smaller communities, however, random fluctuations may obscure the effects and other methods may be needed. "Diary" studies[1], such as those used at the Medical Research Council's Air Pollution Research Unit, or the use of indices based on records compiled by general practitioners after first interviews with patients suffering from acute respiratory diseases, appear to offer the most hopeful techniques in such circumstances. In some communities, however, the population may be too small for satisfactory field studies.

(c) *Long-term effects of pollution.* The long-term effects on man of pollution are generally recognized as being more important than acute reactions. Epidemiological research on this problem involves comparisons between different communities and consequently it is difficult, if not impossible, to exclude the effects of other factors. A critical attitude must therefore be adopted in dealing with the results of such studies. A positive association between chronic bronchitis and air pollution may be accepted, but that between cancer of the lung and air pollution is less certain; indeed, any association appears to be slight, in contrast to that between this disease and tobacco smoking. Further research must include prospective studies so that the incidence of these conditions may be correlated with future variations in air pollution.

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[1] Day-to-day records correlating symptoms with weather conditions.

(*d*) *The immediate or acute effects of air pollution.* The immediate effects are more readily investigated by epidemiological techniques and it is now possible to relate respiratory morbidity and general mortality quantitatively to specific levels of air pollution in certain communities. It may thus be possible to make comparisons between the acute effects of pollution in different communities and between different mixtures of pollutants in the same community.

(3) *Certain specific problems for field studies.* Among the more specific problems needing elucidation by field studies are the influence of acute outbreaks of respiratory infections on the health effects of air pollution, the effects on health of very short periods of high pollution, and an assessment of changing patterns of fuel use, especially in relation to the operation of very large power stations.

(4) *Statistical and epidemiological methods in field studies.* Epidemiology and statistics are becoming more and more effective in dealing with complexities of health data and surveys, and their potential must be reviewed periodically to determine which new techniques are available to improve the methodology of field studies of air pollution.

WATER POLLUTION

Research into water pollution

During the past several years there has been a remarkable increase in many countries in the amount of research on water pollution. This research is being carried out by various governmental, university and private laboratories. Procedures for the sampling, recovery, identification and estimation of organic and inorganic contaminants are subject to frequent review and improvement, and new parameters for estimating the degree of pollution are being tested. The evaluation of the effects of pollution on the quality of water by the study of benthon, plankton and other aquatic organisms and their physiological, biochemical and ecological responses to various degrees of exposure are being intensified; these studies may also lead to the identification of suitable biological parameters for the simple evaluation of degree of pollution.

Epidemiological studies on the health significance of some biological agents and dissolved solids contained in polluted water, which are partially removed by conventional treatment processes, are still under way and no definite conclusion can be drawn as yet. Research into improved methods for preventing pollution includes studies on the origin of various kinds of waste and the assessment of the amount of pollution caused by urban and rural run-off. The recognition that, in many instances, conventional mechanical and biological processes

fail to remove certain contaminants and that there is need for more efficient removal of potential pollutants from liquid wastes has lead to research for new treatment processes, and a considerable amount of experience has already been accumulated in methods for separating a large variety of chemical, biological and radiological pollutants. In almost all instances this has entailed the application of known physicochemical principles, such as adsorption, electrodialysis, ion exchange and oxidation. Although the results of some of these new processes are promising, their cost is still a severe limiting factor, except for special intermittent operations.

Current research

In research on the effects of pesticides, the concentrations of materials to be identified and determined are often very small — of the order of 1×10^{-5} ppm. Identification and determination are possible only by the use of modern instrumental methods, of which gas chromatography and infrared spectrophotometry are examples. Thus expensive equipment is essential, as are the services of specialists trained in its use. To investigate the finer detail presented by the problem, even more complex — and certainly more expensive — methods will be necessary. Clearly, few laboratories are at present equipped to carry out this type of analysis. Nevertheless, there has been rapid progress in the past few years, and interest in the problem is increasing.

In the USA, the realistic approach has been followed of considering the biocoenoses[1] of particular habitats and attempting to evaluate the effects of pesticides on the various links in the food chains that they represent. A similar approach is contemplated in the United Kingdom. It should be mentioned, however, that, although the study of aquatic pollution has been going on for many years, this new problem involves a widening of the disciplines necessary to make up a well-balanced team. If, for example, fish-eating birds are the first members in the food chain to be significantly affected, the team should include a field ornithologist. There is evidence that many substances of importance are adsorbed on insoluble particles; they may then, no doubt, be ingested by bottom-dwelling invertebrates in rivers, lakes, etc., and so enter the food chain Account will therefore have to be taken of the hydraulics of a river influencing the deposition and erosion of bottom deposits. Stagnant bodies of water (lakes, reservoirs) will require special consideration, because through stratification and sedimentation

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[1] A biocoenosis is an ecological unit comprising both the vegetable and the animal population of a habitat.

the local accumulation of undissolved matter or solutes may occur, and also because dilution takes place very slowly as depth increases.

It is well established that different organisms, including fish, are affected to widely different extents by different synthetic organic pesticides. This obviously increases the complexity of the problem and greatly reduces the practicability of using any one species as a universal test organism by which the level of microchemical pollution in an environment and its ecological effects can be evaluated.

The complexity of the present chemical and physical methods for identifying and determining microchemical contaminants poses a particular difficulty where field studies are to be made in remote districts. Efforts are therefore being made to develop alternative procedures, particularly specialized methods of bioassay. In this, notable progress has been made. There is a wide diversity of types of response of organisms to sublethal concentrations of poisons, and workers in this field believe that many biological responses can be used as a basis of bioassay methods. These include, e.g., growth of algal cells, rate of respiration, acquisition of avoidance responses, and level of fertility. There is some hope that with further development of this kind it may become possible to measure not only the relative level of microchemical pollution of a water but also, at least to some extent, the nature of the contaminants concerned.

Published works suggest that measurement of the effect of synthetic organic substances on the rate of growth of algal cultures may yield useful information. Research on this subject is at present in a very active stage of development, and premature standardization of bioassay procedures or test organisms might hinder further progress instead of promoting it. Finally, in order to establish efficient methods for detecting, identifying and monitoring microchemical pollution, there must be adequate baseline data on the ecology of the water systems concerned. This is seldom the case at present and, wherever circumstances allow, every effort should be made to collect such data.

FURTHER EPIDEMIOLOGICAL STUDIES IN MAN

Much occupational health data and experience on more than 350 substances have been used to develop standards for industrial exposures. Such information can be of considerable help in the selection of methods of research in air pollution and in choosing criteria for community air-pollution standards. No general extrapolation of industrial-air standards to community-air standards should be made, because the populations exposed differ greatly.

Use of occupational data for evaluating the hazards of community exposures

Much more information about the long-term effects of certain pollutants that occur in the general environment and also in higher concentrations in that of occupational groups could be obtained if the records of such groups were better analysed. This requires closer co-operation between the industrial medical officer, the industrial hygiene engineer, the epidemiologist and the biostatistician. To make the best use of this and other information, a uniform system of recording is required that will include changes of occupation, residence, period of sickness, and cause of death. This was formerly technically impossible on a national scale but, with the development of computers, may not be so now. It would thus be possible to follow prospectively the morbidity and mortality of groups with known exposure to particular pollutants or groups of pollutants. The establishment of, and access to, such records would be one of the most powerful epidemiological methods for the prospective study of a wide range of medical problems.

In the USA, Social Security Records (BOASI), which were not designed with this end in view, have proved their value in occupational health research, especially for cohort studies. In the United Kingdom, the Ministry of Social Security Morbidity Survey will enable a national study of occupation, residence and sickness from various diseases to be related to indices of pollution. In certain Scandinavian countries, extensive population registers have been maintained for several decades; they already include data on morbidity. This situation is well suited for the carrying out of additional epidemiological research.

Use of available hospital and clinical morbidity data

The long-term effects of environmental pollution on the respiratory system can be studied by the better use of medical records in hospitals and health centres (in-patient and out-patient departments) as well as of pathological reports. A higher incidence of some communicable or infectious diseases among children and the working population has been reported in areas with higher air pollution. Further knowledge of the prevalence of chronic inflammatory throat diseases and chronic bronchitis, as well as cor pulmonale, can be obtained in some localities from data on hospital admissions and aut-patient examinations. Such research is not being fully exploited and ought to be encouraged. More explicit and uniform diagnostic criteria, both in clinical and in pathological work, are needed, as well as more precise and uniform data on exposure, including the type and amount of pollutants, time and type of exposure, and demographic and other data on the population at risk.

The diseases to be investigated should include chronic throat diseases, chronic bronchitis, asthma, emphysema, pulmonary fibrosis, cor pulmonale and cancer.

Attention should be drawn especially to population groups under special health care, such as cardiac and emphysematous patients, and healthy groups under special preventive care, such as schoolchildren, pregnant women and athletes.

In these groups some special simple physiological studies should be recommended as part of routine follow-up examinations. The findings for areas with different pollution levels could then be compared.

This kind of work will be of greatest value when adequate environmental data are also obtained.

Behavioural studies

Much work on conditioned reflexes and on sensory physiological responses to pollutants has been carried out, particularly in the USSR. It has been suggested that such responses in general may provide very sensitive indicators of low-level effects. However, their usefulness in evaluating long-term effects is probably limited. Some attempts to confirm the results of these studies, particularly with respect to solvent vapours, suggest that the procedures are relatively insensitive. Further exploration should be made of their value for both short-term and long-term exposures.

Prospective surveys for evaluation of long-term effects of air pollution

Because of the complex and varying composition of air pollutants in different places and the possibly important effects of climate, it is desirable to carry out epidemiological investigations on a larger scale and in more places than previously. To ensure that such results will be comparable and informative, certain steps are essential: first, an adequate description of exposure, second, a valid measure of medical effects, based on an adequate population sample, and third, a satisfactory follow-up method.

The investigation must be an ecological one, i.e., one based on studies of both exposure and morbidity within a considerable number (hundreds) of districts. These districts should be selected to give the maximum variation in dose (exposure) and climate. Statistical design and population sampling can provide other criteria for selection.

When selecting districts for the investigations it will be necessary to make a preliminary study of the relevant variables in a considerably larger number of districts, particularly in respect of the concentrations

of the most important pollutants and data available on the population structure.

The second problem concerns the measurement of effects. Detailed medical examinations of a population sample are not always feasible, and it would not be satisfactory to rely on existing official statistics of morbidity and mortality. A study should be made, therefore, of the feasibility of using mailed questionnaires to obtain an estimate of the relevant information on respiratory and cardiovascular symptoms. Such an approach has already been tested in some countries and merits further exploration.

If a study of this type is to be practical, the requirements for completeness of information about all symptoms ought not to be set too high. Attention is called to the questionnaires on respiratory symptoms approved by the Medical Research Council's Committee on the Actiology of Chronic Bronchitis.[1] The inquiries should be fitted into a model of this or a similar type — with as much consideration as possible for comparability in the evaluation of exposure and effect.

A check on the validity of the approach will be needed. This must be done by personal interviews and by a simple clinical lung-function test ($FEV_{1.0}$) and environmental exposure estimates for a limited subsample of the populations and areas. Such methodological studies should be started as soon as possible, as pilot operations, along with training in the use of questionnaires, possibly including the use of tape recorders. Such pilot operations provide a means of testing intra- and inter-observer variability, and of selecting questions and interviewers.

Although the above procedures will permit additional estimates of prevalence, serial observations of two types may be useful in order to evaluate incidence. The first will consist in repetition of the same inquiry (mail or personal interview) and test, using precisely the same methods and interviewers or examiners; in addition, more information on bouts of disabling respiratory disease should be obtained, if possible, from health records. Such a procedure also provides a means of evaluating interviewer variability. A second follow-up method consists in determining, by comparison with official records, the time and cause of disability, retirement or death. Such "death clearance" or "retirement clearance" studies are tedious if carried out by hand, but can be done on computers with greater facility.

[1] Further information can be obtained from the Department of Medicine, Postgraduate Medical School of London, Ducane Road, London, W. 12, England.

7. PROBLEMS ON WHICH RESEARCH IS REQUIRED

ENVIRONMENTAL POLLUTION IN GENERAL

In outlining research on the health effects of environmental polluti
priority has been given to the combined effects of air and water p
lution, but the effects of food and soil have also been taken into c
sideration where appropriate.

Greater efforts should be made to relate the kinds and amou
of pollutants from all types of environments with levels of polluta
and their metabolites in body tissues and fluids and with health eff
in man and animals, using epidemiological and laboratory metho

Ways should be sought of increasing the reliability of extrapolat
of experimental and animal data to pollutant effects on man.

The study of the general problem of the body's defences aga
pollutants, especially at low levels, and the related problems of ad
tation should be pursued vigorously, both in animals and in m

The role that absorption, distribution, storage and excretion p
in pollutant toxicity should be more widely and thoroughly stud

Increased research attention should be given to substances suspe
of having carcinogenic, mutagenic or teratogenic effects.

Increased attention should be devoted to the study of the eff
of pollutants on aging and shortening of the life-span.

Industry should be encouraged to consider, in the developm
of new products, not only their utility and safety in use, but also
likelihood of their contaminating the environment after they have b
used. Manufacturers should, for example, consider the degradabilit
detergents by biological action and the possible nature of the combus
products of plastics.

Characterization of pollutants

The environmental pollutants that should be determined are
air, organic compounds of sulfur and nitrogen, halogenated hydrocarb
and other halogen compounds, metals and metalloids with poten
effects on health; in water, beverages and foods, identifiable pestici
metals and metalloids.

Estimation of body burden

Systematic surveys should be carried out in as many countrie

possible of the metal, pesticide and other organic pollutant content of human tissue, including blood and urine, with special attention to lead, cadmium and pesticides. Estimates of the environmental exposure to these substances from the air, water and food, from smoking and from occupation should be made simultaneously wherever possible. Similar data on wild and domestic animals should also be sought.

Follow-up of heavily exposed populations

Controlled long-term follow-up studies should be made among defined populations subject to unusually high exposures to pollutants that may affect the general community. Such exposures occur both in occupational groups and in local groups of the general population, e.g., traffic policeman exposed to unusually high concentrations of lead; populations near metal refineries in locations where the chromium level in the drinking-water is high or where coal of high arsenic content is used; workers exposed to ozone in cold-storage plants, to mercury in and around alkaline chlorine plants, or to carbon monoxide in steel mills. The aim of all these studies should be to detect small deviations from normal function, using sensitive physiological and biochemical methods as well as differences in morbidity and mortality.

Study of populations with unusual exposures to insecticides

Retrospective and, especially, prospective epidemiological studies should be made in groups exposed to unusual amounts of chlorinated hydrocarbons, organophosphates and other pesticides. One such population is that near Ferrara, Italy. These investigations will be more valuable if they are co-ordinated with studies of the effects of pesticides on the fauna in the area. Studies should be included of possible chronic and indirect effects of absorption of the pesticides. Similar studies would be particularly appropriate in areas where pesticides are used intensively in conjunction with malaria eradication programmes.

Development of postal questionnaire methods

A study should be made to test the feasibility of a cross-sectional survey of respiratory and cardiac (and possibly eye and skin) symptoms, using a standardized mailed questionnaire, in a large number of population groups in different countries. The areas chosen should have large differences in pollution and climate. Standardized measurements of

pollution will also be required and a system will be needed for inter-
viewing a sample of the population to check the validity of the mailed
questionnaire and to confirm the histories of exposure.

Possible relationship of cor pulmonale to pollutant exposure

Further international comparisons should be made in selected
hospitals of the proportion of the admissions with cor pulmonale, and
of its incidence at autopsy. Standardized criteria will be required for
diagnosis in life and at autopsy.

Intensive study of epidemic respiratory allergies

Episodes of local air pollution suspected of being related to "epidemic
respiratory allergies" should be investigated.

Uniform occupational exposure data

Full elucidation of the long-term effects on health of pollution
(and of all other environmental factors) requires a continuity of infor-
mation about the individual and his environment over a life-time.
Countries should be encouraged to develop uniform and comparable
records and make them accessible for health research so as to pool
information on occupation, residence, sickness and death of individuals
and population groups.

STANDARDIZATION OF OBSERVATIONS

Standardization of laboratory methods

The development and standardization of methods of laboratory
investigation should be concerned with at least five factors: (*i*) wider
use of new analytical methods for pollutants, (*ii*) development of
mathematical models for estimating integrated doses of pollutants,
(*iii*) comparison of methods of measuring physiological and biochemical
responses to pollutants, (*iv*) development of new measures of response,
and (*v*) rapid screening methods for identification of health hazards
associated with new chemical pollutants.

Standardization of epidemiological methods

Reference centres should be designated to develop, test and stand-
ardize epidemiological methods for investigating the long-term effects

of pollutants. Initially attention should be given to questionnaires, both personal and postal, for studying respiratory reactions to pollutants. Such centres should also train personnel in standardized methods, develop standard methods for measuring exposures in the populations studied and, through contact with field operations, maintain comparability between studies.

ANIMAL EXPERIMENTS

Experimental exposures to realistic pollutant mixtures

Animal exposures should be performed using realistic mixtures and levels of air pollutants and simultaneously using water and food containing amounts and types of contaminants likely to be encountered in practice. In addition to toxicity, effects on social behaviour, aging and life-span should be studied.

Large-scale experiments

In order to improve the reliability of extrapolation of low-prevalence events for predicting human health hazards, the use in selected experiments of large numbers (thousands) of animals is recommended.

Effects of pollutants in combination with infection

Selected experiments should combine exposure to pollutants with exposures to infectious agents, both naturally occurring and experimentally introduced. Studies should also be carried out in animals with specific organ impairment or general debility.

Epidemiological studies in animals

Epidemiological studies of pollutant effects should be made on the natural environmental receptors of pollution and wild and domesticated animals, in the latter case through co-operative veterinary research. Work on the development of new inbred strains and new species of animals for the laboratory investigation of pollutant effects should be intensified.

ENZYME STUDIES

Role of enzymes in adaptation to pollutants

Further steps should be taken to determine which pollutants stimulate the production of adaptive enzymes in animals and man, with special attention to repetitive stimulation, as part of an over-all effort to understand the defence mechanism of the body against pollutants. Differences in response in different host species and strains should be determined; the effects of age on these relationships should be evaluated. Research on the mechanisms of these changes is also needed.

Immunological reactions to pollutants

Research should be continued to determine the nature of the immunological responses to pollutant exposure, which pollutants have important effects in this respect, and the effects of pollutant combinations on the immunological process. Research should be continued and extended on the immunological effects of infection, deliberate and natural, superimposed on pollutant exposures.

Other adaptive mechanisms

Investigations should be made of the ways in which the central nervous system contributes to the maintenance of homeostatic equilibrium and thus to defence and adaptation to pollutant exposures. Efforts should also be made to find ways of improving the natural defences against pollutants and of improving the adaptation mechanisms of the body.

METABOLISM OF ABSORBED POLLUTANTS

Investigations should be extended on the absorption, distribution, metabolism, storage and excretion of environmental pollutants; attention should be paid to such routes of entry as skin and respiratory and gastro-intestinal tracts. The studies should be focused on groups or types of compounds, e.g., the carbamates or other newly introduced pesticides, the epoxides, the more important aromatic amino and nitro

compounds, alkyl nitrosamines, and other substances with carcinogenic, mutagenic or teratogenic potential, certain halogenated substances, aerosol combinations, and metals and metalloids.

CARCINOGENIC AND MUTAGENIC STUDIES

Research on the carcinogenic and mutagenic potential of pollutants should be directed to the effects of five factors: (*i*) route of entry, (*ii*) metabolic transport, (*iii*) species differences, (*iv*) promoters or accelerators, and (*v*) dose-response relationships. Research to determine teratogenic effects should be initiated with the object of establishing the lowest dose of the agent from water or air pollutants that will produce effects.

LONG-TERM EFFECTS OF POLLUTANTS ON AGING

Research on aging or life-span shortening effects should (*a*) screen pollutants in order to determine whether such effects are likely and, if so, the dose-response patterns, (*b*) determine the processes by which these effects occur, and (*c*) attempt to establish criteria for defining the aging process.

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